Prevention of Failures of Tube-Wells and Study of Recent Technique of Construction for Improved Performance

A Thesis submitted in partial fulfilment
of
the requirements for the degree
of
Master of Engineering
in
Applied Thermodynamics (Power Engineering-Steam and I.C. Engines)

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C E R T I F I C A T E.

Certified that the Thesis entitled "Prevention of Failures of Tube-wells and Study of Recent Technique of Construction for Improved Performance" which is being submitted by Sri Bindeshwari Prasad Hajeley in partial fulfilment for the award of the degree of Master of Engineering in Applied Thermodynamics (Power Engineering - Steam and I.C. Engines) at the University of Roorkee, is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of about four and a half months from 1st May 1963 to 15th September, 1963 for preparing this thesis for Master of Engineering Degree of this University.

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References have been made to various authors in the present text. Care has been taken to acknowledge the reference wherever it occurs. Any departure from this is un-intentional.

PREVENTION OF FAILURES OF TUBE-WELLS AND STUDY OF RECENT TECHNIQUE OF CONSTRUCTION FOR IMPROVED PERFORMANCE.

C O N T E N T S.

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"SYNOPSIS"

India is an agricultural countfy and its farmers are poor. To make the country prosperous and industrially advanced, we need a strong agricultural back-ground which in turn needs more water for irrigation. With the near exhaustion of economical sites for tapping river water for canal irrigation, the attention of engineers was drawn to another huge source of water i.e. ground water. The ground water is brought on surface for use through tube-well system. Our aim in this system should be to pump out ground water most efficiently and economically so that it is reasonably cheap and should, therefore, be utilised to maximum extent by poor farmers. This can only be done if the wells are designed scientifically.

The Government of Uttar Pradesh introduced the tube-well irrigation scheme in the Western Region of the State as early as 1935. This brought all round development of the region. Subsequently more schemes were introduced in other regions of the state but it did not become popular with the cultivators due to its higher cost as compared to canal rates. All through this period the construction of wells was largely guided by tradition and individual experience. There were large casualties due to excessive sand discharge, rupture of screens, etc. The average life of the well was also low, about 16 years, as compared to average life of wells in similar stratas in U.S.A. which is about 35 to 40 years. And as such the tubewell scheme has not proved very economical to the government.

In order to ascertain the nature and extent of failures due to various reasons, the author carried out survey of State Irrigation wells of the Western region of Uttar Pradesh comprising the districts of Saharanpur, Muzaffarnagar, Meerut and Aligarh where more than 1200 State wells are located. Records of about 200 typical wells (App. B) were examined. The examination revealed that

I. Maximum number of failures of wells was due to excessive sand discharge and ultimate screen repture.

II. The next in order was due to screen clogging and consequent depletion of yield.

III. Some cases of screen failure due to corrosion were also noticed.

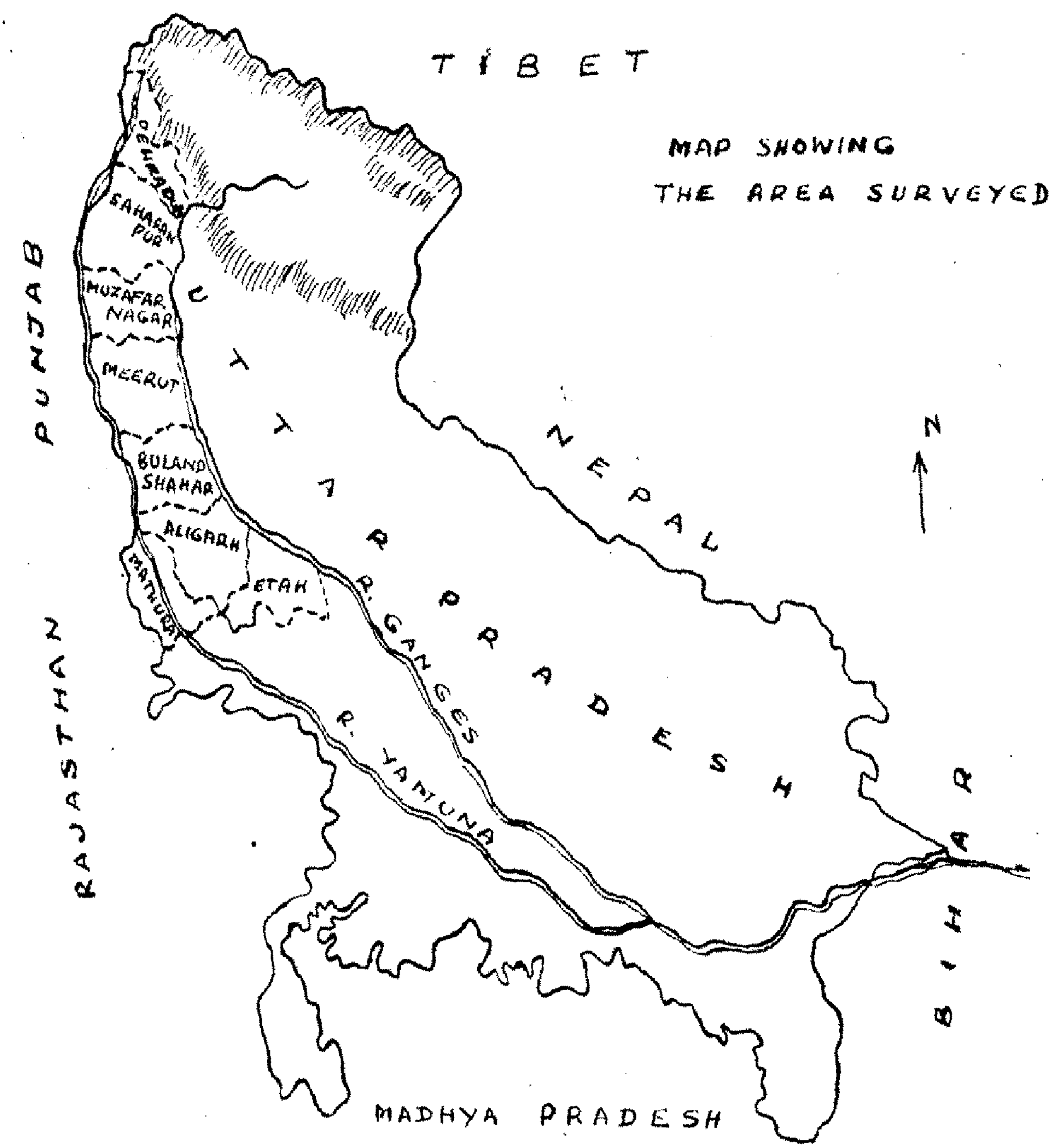
The average life span in all the three cases was poor (App. B). There was considerable average fall of discharge and consequent loss in revenue (App. A).

The main cause of the poor performance of the wells as demonstrated by the survey results was that :

I. The geological formations were not interpreted correctly.

II. The wells were not constructed scientifically

III. Material used in the structure of wells was not of desired quality confirming to the specified requirements of the job.


TIBET
MAP SHOWING
THE AREA SURVEYED
PUNJAB
DEHRADUN
SAHARANPUR
MUZAFARNAGAR
MEERUT
BULANDSHAHAR
ALIGARH
MATHURA
ETAH
UTTAR PRADESH
NEPAL
N
R. GANGES
R. YAMUNA
RAJASTHAN
BIHAR
MADHYA PRADESH

It appears that this was due to the fact that science of tube-well construction was not devoloped so much by that time. But, unfortunately, even now very little published data on the subject is available in our country and very little scattered efforts are being made to provide the tube-well a sound technical basis.

The author in this paper has tried to approach the subject scientifically and has analysed and incorporated the latest thinking and technique regarding :

I. Design aspects of tube-wells for efficient performance, better economy and longer life.

II. Methods of prevention of undesired failures.

The well performance is governed by two of its major components :

I. The formation of the under ground in which the well structure is located, and

II. The well structure itself.

Both of these components have different characteristics. Wells built in accordance with theoretical considerations governing their performance will give results in accordance with those principles depending upon how closely they have been observed. The paper, therefore, deals mainly (1) with the geological formation and its hydraulic characteristics as related to design of deep-wells (Chapter I & II) and (2) proper design of well structure to achieve economy and longer span of life (Chapter III & IV).

The salient features of each chapter are :

Chapter I deals with the characteristic of geological formation and its influence over the well performance. Its proper study and correct interpretation in design for better yield and improved efficiency.

Chapter II deals with the development of fundamental equations of ground water flow, relation between wall discharge and draw-down and the influence of the following features on well design.

I. Hydraulic characteristics of the formation.

II. Significance of water table and its correct interpretation while locating the wells.

III. Well losses.

IV. Technique for separating the losses and determining the cause of trouble in a wall.

V. Recent techniques of well drilling have been dealt in Appendix 'D'.

Chapter III deals with the most important component of the well structure i.e. screen which has scientifically been discussed. The well life and its economical performance, as a matter of fact, depends entirely upon the behaviour of its screen in the same way as the entire crop depends upon the behaviour and quality of seed, though it may not form a major share of the total expenditure.

The following important aspects of a screen have been dealt in order to have better design conditions for elimination of possible causes of failures and consequent longer life.

I. Losses incurred in the screen.

II. Sand movement into screen and its prevention.

III. Structural strength of screen.

IV. Problem of corrosion and incrustation in screens and their prevention.

V. Proper design of screen dimensions. Size and shape of screen openings.

VI. Suitable type of screens on the basis of discussions and results are recommended.

Chapter IV deals with the gravel type of wells. Proper design criteria for the matching of gravel size, slot size and shape and its orientation so as to incur minimum head loss and maintaining its sand screening characteristics in a gravel pack have been discussed.

Chapter V deals with the prevention of failures and discusses the recent techniques for improving the performance of partially failed wells such as chlorination, calgon treatment, surging, air treatment and vibratory explosive method, etc.

In the end of the paper, appendices A, B, C and D are given.

In appendix 'A' is shown the advantages of using a better designed and costly screen as compared to ordinary strainer now in vogue.

In appendix 'B' is given the data of tube-wells collected from various districts. Graphs showing the comparative performances of wells of different districts, rate of survival, etc. have also been given.

In appendix 'C' sieve analysis test of sounds of more than a dozen wells have been given. Suitable recommendations for selection of proper size of screens have been made in it.

In appendix 'D', some recent methods of drilling of wells have been discussed.

CHAPTER I

GROUND WATER

&

GEOLOGICAL - FORMATION.

1.1 INTRODUCTION: Broadly, speaking, tube-well system is a process by which the ground water is brought on ground surface for beneficial use by mankind. The most acceptable definition of ground water seems to be set out in U.S., W.S.P. 494 by Dr. Meinzer, when he says " Ground Water may be regarded as measuring the basel or bottom water." Most commonly, we can say, that water found below the water table, is the ground water.

1.2 EARLY HISTORY: Records are vailable to show that early Egypitans and people of many other countries were familiar with drilling methods for putting down tubular holes into ground to obtain ground water (1) During middle ages, there was little or no development in drilling of wells. A 200 feet deep well known as St. Patrick's well, was drilled in Italy in 1540 A.D. and furnished a plentiful supply of water. In U.S.A., the development of ground water started only about 80 years back. In India, interest in deep well drilling was taken about 35 years back and since then thousands of wells have been drilled either for irrigation or drinking purposes and the cost involved runs in crores of rupees.

1.3 USE OF GROUND WATER: It can be utilised in great variety of purposes including public institutions, hotels, factories, canneries, dairies, power plants, recreation establishments, etc ; cooling and air conditioning plants in future will definitely make heavy demands on ground water because of its characteristic uniformity in temperature. The consumption of ground water is bound to increase manifold with the progress of country.

1.4 By tube-well pumping, we can withdraw the ground water year after year. But this ground water reservoir is ours for beneficial purposes, there is no advantage in letting it go to waste if it can be made to serve human welfare. Therefore now the question arises as upto what extent the water can be withdrawn, to what extent it is replenished and to what extent it is merely taken from ground storage and how efficiently. Answer of these problems lies in scientific development of the subject.

1.5 SAFEGUARD: We must guard against the depletion or spoiling of our extremely valuable under ground reservoirs. The conservation and efficient use of these natural reservoirs of water should be our major national problem and it must be immediate and urgent.

1.6 Engineers and government departments must share the responsibility in tackling this problem. The government departments may carry out scientifically, the accurate ground water investigations and then publishing results for the enlightenment of the public. Engineers should strive for proper location, spacing, use of better materials, improvements in drilling, equipments and methods of construction. Besides, engineers must be able to give a useful life of about 50 years to a well for better economy and must be able to check deterioration and failure of wells.

1.7 **SCOPE:** Traditionally, India is an agricultural country and about 80% of its population depends upon cultivation. The basic need of the country, therefore, is the water fro irrigation. Many irrigation schemes were visualized and were put into operation during the last century and many more schemes were and have been taken in the three five year plans to supply irrigation water from sources like rivers, lakes, reservoirs, etc. Not many sites are now left for harnessing the rivers economically for irrigation purposes. But, even now after so many schemes the success of the crop depends very much upon the whims of nature i.e. monsoon.

1.8 Even after completion of irrigation works which are in hand, a large percentage of our productive land will be left which could not be provided with canal irrigation system. Some areas, due to its location and topography with respect to water supply by canals make the canal system extremely costly. The answer to such problems lie in harnessing the ground water by tube-well pumping.

1.9 **OCCURRENCE OF GROUND WATER:** Except the great oceans, the water in maximum quantity appears underground. Sir Cyril (2) has estimated that if the volume of ground water available is spread over the land surface, it would drown it to a depth of 100'. If added to oceans, it would raise their level by 40.76'. Thus we can see that what a huge amount of ground water is available at our command to be pumped out through tube wells. Engineers can definitely ensure a plentiful carefree supply of irrigation water to our farmers and make them independent of the vagaries of monsoon.

1.10 ADVANTAGES OF TUBE-WELL SCHEME. An attractive feature of tube-well irrigation scheme is that, it can be developed gradually and units can be placed in areas where they are in demand and likely to be immediately useful. Another satisfactory feature is, that tube well cannot cause water logging and deterioration of soil. On the other hand, it improves the tract by slightly lowering any inconveniently high spring level. Tube-well water being slightly more costly, is carefully utilised in the right proporation by the cultivators and there is comparatively less wastage by them and in channels.

1.11 ECONOMY AND SUCCESS OF WELL SCHEME: Farmers in our country are very poor and they cannot afford to utilise costly water. Our basic aim must, therefore, be to find out ways and means for pumping out and supplying reasonably cheap water. Besides, its continuity must also be ensured. Cheap pumping can only be achieved by approaching the problem scientifically and designing every component of the tube well scheme properly. It is possible only when the government departments and the tube-well engineers work in close co-operation. The government departments should carry out the survey of ground water resources and should make the following information available to public for easy reference:

(1) Details of geological formations such as consolidated, semi-consolidated or unconsolidated and their extent.

(2) Fluctuation of water table over a large period.

(3) Yield capacity of water bearing formations of different regions.

(4) Permeability of different regions.

(5) Quality and extent of mineral contents of ground water of different regions.

The engineers can make the scheme officeint, economic and better remunerative by:

(1) Proper design of straight screen or gravel pack wells.

(2) Proper choice of materials to withstand corrosion and deterioration over a large period say 50 years approx.

(3) Proper location and spacing so as to get maximum continuous yield for the whole life of the well.

(4) Better, economic and efficient well drilling techniques.

(5) Proper selection of pumping equipment.

(6) Devising methods for improving the yield of old wells so as to avert premature failure because it increases the cost of the scheme ultimately and make the water production more costly.

1.12 Large scale tube-well schemes for irrigation were started by the Government of U.P. from 1955. There are, at present, more than 8000 State tube-wells besides a large number of private tube-wells in this State. More and more new schemes are being envisaged which calls for greater amount of public money. This naturally imposes a heavy responsibility on engineers in charge of such schemes.

1.13 SCIENTIFIC WORK: Enough scientific work has not been done in this country so far on the design of tube-wells. There are very few published articles available on this subject. A. Sanghi (3) and K.L.Jain (4) recommended certain design criteria based on statistical data. Prof. R.S.Chaturvedi (5,7) made investigations for the proper design of Radial and Shrouded wells. Important researches on gravel-pack wells are also going on at present in the Irrigation Research Institute, Roorkee, under Mr. P.N.Gupta, Research Officer (6) Uptil now, however, the design of tube-well in this country largely depends upon individual experience and tradition.

1.14 WELL CONSTITUENTS: There are three main constituents of a well:

(a) Formation i.e. geology of the area.

(b) Well structure i.e. screen assembly and

(c) Pumping equipment.

All these constituents have a decisive influence on the overall performance of a well. Seperate study of the behaviour of each part is, therefore, essential before finally deciding upon the line of action.

1.15 WATER BEARING FORMATIONS: Wells are generally constructed in two types of formations - the unconsolidated rocks such as clay, shale, gravel and sand and the consolidated rocks such as lime-stone, sand-stone, granite etc: First type of formation is mostly found in the Gangetic Planes of Uttar Pradesh State. However, the second type is also found in places like Bhabar area of Nainital District and Doon Valley etc. The author has drilled a well in Village Hariharpur near Haldwant - Bhabar area and the second type of formation was largely met. The spring level at this well was about 165 feet from ground level.

A careful study of geological formation of water bearing Strata is always very essential because on it depends the success of a well.

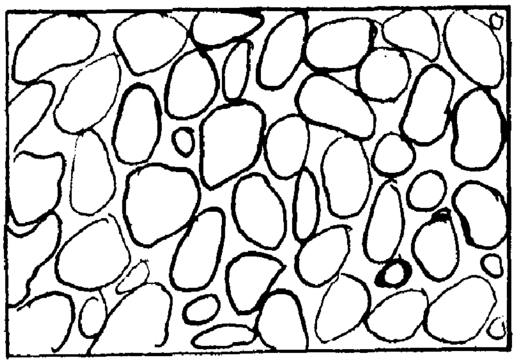
1.16 GRAVEL AND SAND FORMATIONS: Well graded gravel deposits free from sand cannot be approached for quantity by any other formation. Well yielding as much as 1,200 gpm per foot of depression has been constructed (8). This type of formation absorbs water-freely, stores it in large quantities, and yields it readily. Porosity and permeability of a sand gravel formation guides its behaviour regarding its capacity to absorb and to yield. During drilling we find a wide range in the size of particles in the average sand gravel formation as well as in their water bearing abilities. Amount and kind of assortment of particles and kind and amount of cementation decisively affects the yielding capacity of the formations.

1.17 SIZE OF GRAINS: The coarser and more uniform the particles of a sand-gravel or sand-stone formations are graded, the more water it will yield. On the other hand, if the particles are fine like those in silt, then little or no water can be obtained as the formation will not give it up due to adhesion and surface tension. The size of individual grain is, therefore, important and controls considerably the amount of water that can be obtained. It must be well understood that it is the percentage of fine minute particles that determines the yielding ability and not the large particles, because the fine particles occupy the voids formed by the larger particles and still finer particles occupying the void formed by the small fine particles. The particles of sand-gravel formation are generally pieces of silica, flint, quartzite, limestone, granite, dolomite, etc. The sand which is generally found mostly contains silica.

1.18 CLAY: It is one of the most common material encountered during well drilling. Pure clay is made of very minute particles and appear to be solid. When wet it becomes plastic and smooth to touch. The mineral contents in the clay determines its colour. Mostly the clay particles are of aluminium silicate. Clay is very difficult to remove from a sand formation as it clings to the larger particles and has a tendency to become pasty forming balls and chunks which are almost impossible to break down. Sometimes clay is found in layers of many feet in thickness. As a rule the clay in a mixed formation generally lowers its yielding capacity and should be avoided.

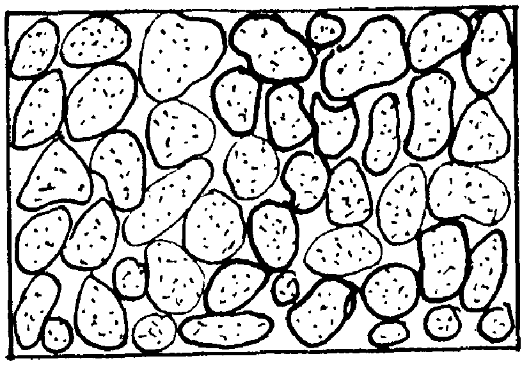
FIG. 1.22

A



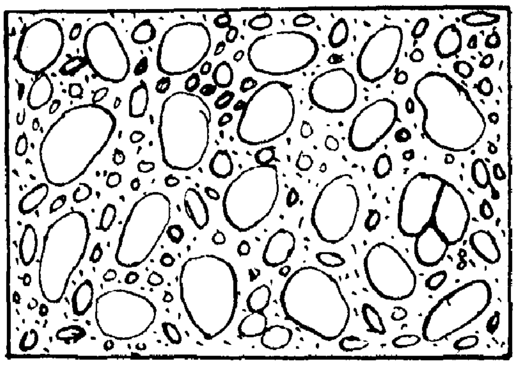
WELL SORTED SEDIMENTARY DEPOSITS - HIGH POROSITY

B



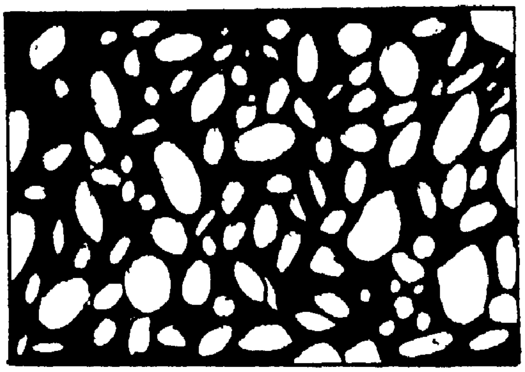
WELL SORTED SEDIMENTARY DEPOSITS WHICH ARE THEMSELVES POROUS - VERY HIGH POROSITY

C



POORLY SORTED SEDIMENTARY DEPOSITS - LOW POROSITY

D



WELL SORTED SEDIMENTARY DEPOSITS WITH MINERALS - POOR POROSITY

1.19 SHALE: Another typical material of sedimentary origin is shale which is a true clay formation or clayey mixture that has become hardened. It is definitely a non-water bearing formation with few exceptions such as joints and bedding planes and must not be tapped.

1.20 ALLUVIUM: The " alluvial deposits" which are sand gravel deposits vary from the finest particles of sand upto boulder mixed with clay and silt. Sometimes a formation of coarser particles only is found. But to get a sand free supply of water in larger quantities from alluvial formation, it is necessary that finer particles of sand be removed first. It is a good water bearing formation.

1.21 SAND-STONE: It is another type of water-bearing formation and is composed of grains of sand (mostly quart) bounded together with a cementing agent like carbonates of silica, calcium and iron oxide. The yielding ability of sand stone closely follows that of sand of the same characteristics.

1.22 INFLUENCE OF POROSITY: Porosity is defined as the percentage of total volume of formation that is occupied by pores or interestices.

Schilicter from his experiments established that:

(1) If all other conditions remain the same , a material will have the same porosity whether it contains larg or small grains.

(2) Irregularity of shape results in a large variation in porosity.

(3) Variety in size of grains is of fundamental importance with respect to the porosity of a deposit.

The above statement implies that porosity of the unconsolidated formation will depend upon:

(1) Degree of assortment of its particles.

(2) Shape and arrangment of its particles.

(3) Cementation and compaction.

(4) Removal of mineral matter by percolating water

1.23 Well sorted, clean, uncemented gravel sand or silt will have high porosity. Also a deposit composed of large grains of uniform size and a deposit of small grains of uniform size both will have an equally high porosity. On the other hand, a deposit composed of grains of two sizes has a low porosity (fig. 1.22).

1.24 The porosity of different materials varies over a large range from less than 1% to 50%. A porosity of 5% or less is regarded as low, between 5 to 20% medium and greater than 20% as large. The porosity of graded and ungraded sand determined by Hickox and others (16) is as follows:-

Characteristics of Graded Material

Mean Dia.	Fluid	Range of porosity %
.000865 ft	Water	40.2
.0378 ft	"	36.5
.000442 ft	"	49.8
.000832 ft	"	45.1
.00160 ft	"	43.3 to 48.4

Characteristics of uniform materials.

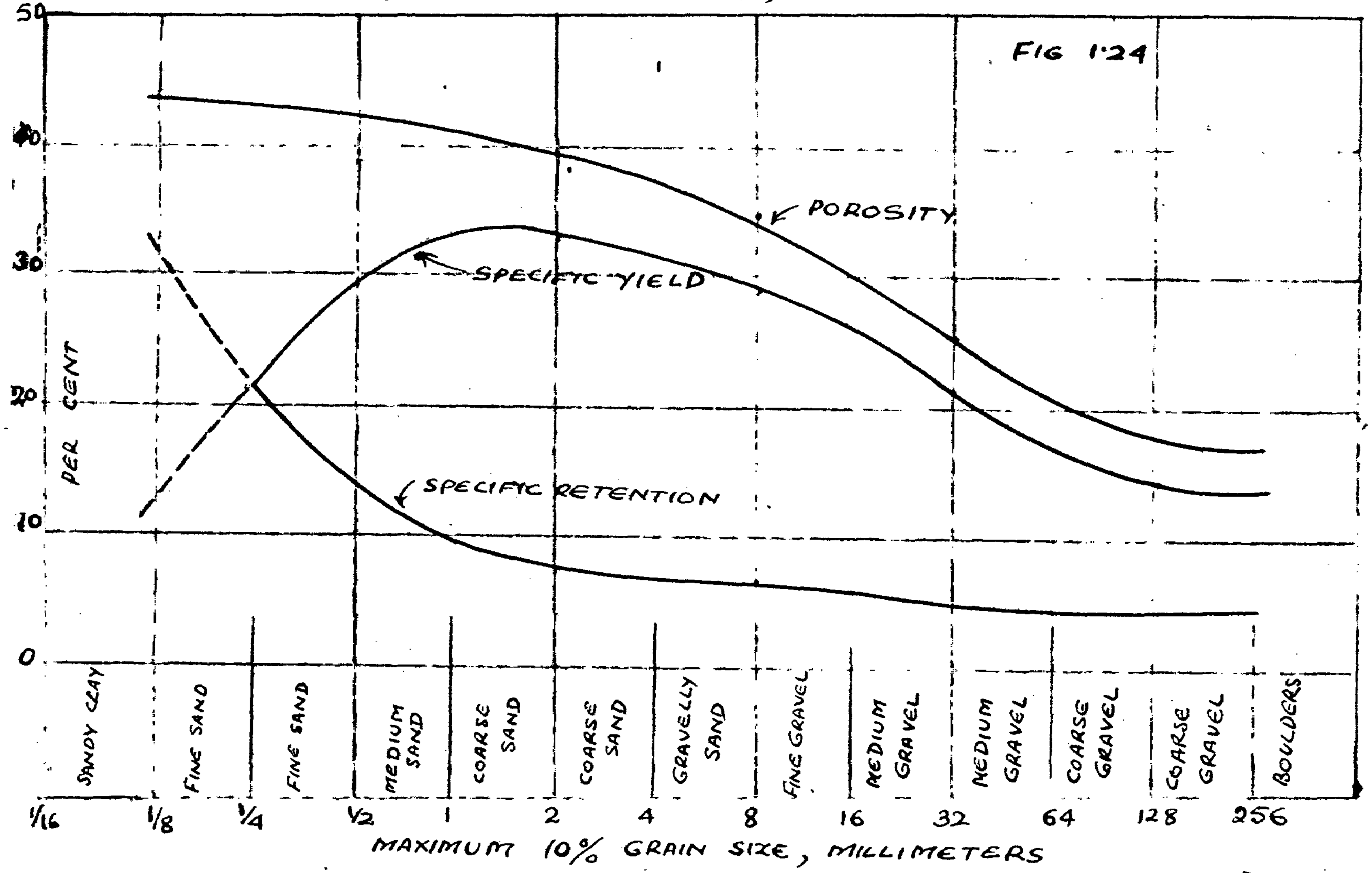
Range of dia.	Fluid	Range of porosity %
.00094 ft	Water	35.2 to 38.7
.00036 ft	"	
.00816 ft	"	35

Perfect spheres of equal size can be arranged upto a porosity of 47.6%.

1.25 Knowledge ofporosity is important whenever

VARIATION OF POROSITY, SPECIFIC YIELD AND SPECIFIC RETENTION WITH GRAIN SIZE

(THE GRAIN SIZE IN WHICH THE CUMULATIVE TOTAL, BEGINNING WITH COARSEST MATERIAL, REACHES 10% OF TOTAL SAMPLE)



investigation are to be made of an area for its water yielding possibilities. It tells the ability of the formation to contain water and its ability to yield the water it contains to a well. It can be determined by prevelent standard methods exactly or approximately.

1.26 SPECIFIC YIELD AND SPECIFIC RETENTION:- On account of adhesion, surface tension and capillarity, it is clear that all the water from the formation cannot be extracted by any means. However, the aim for getting the maximum yield from the depth of the well must be there. Specific yield and specific retention are expressed as percentage volume of water yielded or retained by the formation. Thus 100 cft. of saturated formation when drained by gravity supply 25 cft. of water, then the specific yield is 25% and if 15 cft of water, is retained by the formation, then its specific retention is 15%. The sum of the specific yield and the specific rentention is the porosity of the materials.

1.26 INFLUENCE OF FORMATION ON DESIGN OF WELL: From discussions of para 1.18 and 1.19, it is clear that the clay and shale formations are not suitable for locating the well as they will yield very little or no water and that too against very great resistance. Formation having a large percentage of clay will reduce its porosity and its capacity to store and yield water and therefore are not suitable. Gravel, Sand, Alluvium and sand stone formation are good water yielding stratas (Paras 1.16, 1.17, 1.20, 1.21) and wells should be located in such formations. Water yielding capabilities of these formations will be largely guided by the percentage of fine particles which they may contain. The quantity of fine particles also influence the choice of screen openings (discussed in Chapter III) and can be determined by a mechanical sieve test and it is also a deci-

deciding factory in determining whether the well should have an ordinary straight screen or be a gravel pack well (discussed in Chapter IV)

1.27 The geological formations underground are natural and nothing can be done to alter their properties. Therefore, before going of for a well following tests should be carried out which will prevent many difficulties of future.

(1) Pilot boring to obtain the strata samples for study and analysis of aquifer.

(2) Sieve tests for each case so as to determine the size, degree of assortment of sand and, therefore, the design of screen.

(3) Permeability tests which will determine the yield.

(4) Chemical analysis of dissolved, substances which will influence the choice of material.

The importance of permeability has been discussed in detail in Chapter II.

1.28 During the survey of wells, the author found that no sieve tests of formations were done on wells previously constructed and this was one of the main reason of their faulty behaviour. But now at certain places, the sieve tests are being done but still at some other places rule of " tourch and see" method persists which is extremely dangerous to the well performance and life and must be stopped forthwith.

1.29 The chemical properties of ground water also plays an important part in the design of wells. Ground water contains many impurities which cause corrosion or incrustation of well screens. Special corrosion resisting materials have been developed for use of tube wells. The problem and methods of prevention of corrosion and incrustation are discussed in detail in Chapter III.

1.30 WELL-STRUCTURE: Dennison (8) has rightly pointed out that wells as engineering structures serve one purpose only and that is to transmit or make available for economical pumping the largest possible amount of water from the formation in which they are constructed. The performance of a well depends on many things such as the methods and materials of construction, the design of screen, the amount of development, work done and rate of pumping after the well is in operation. Each of these factors influence the performance greatly and must be considered carefully in designing the construction of a well (Discussed in detail in Chapter III)

1.31 PUMPING EQUIPMENT: Two types of pumps-centrifugal horizontal pumps and deep bore turbine pumps - are generally used in India for irrigation pumping from a deep well. Before installing a pump, the engineer should have a definite performance picture of the equipment which he is going to install. Since the wells for irrigation have to run day and night for most of the part of the year, their efficiency must naturally be sufficiently high and must remain so over the pumping period for better economical running. High efficiency and low cost do not go together in the manufacture of pumps and, therefore, the valuation of the equipment must be made on the basis of long term economy. While doing an initial test on a well, the use of a new pump should be avoided if the well has not been completely cleared of land, mud, sludge, etc., Because the damage done by them to the pump in few hours of testing may be equal to the damage in 5 years or so.

SUMMARY: From the discussion of para 1.15 to 1.27 it is clear that the geological formation and its correct study plays a decisive role on the design and life of a well. It was found from the survey of wells that in general no physical or chemeical analysis of the formation was done when the wells were constructed. On strata charts of these wells, the formations were defined in vauge terms, such as, fine sand, medium sand, fine to medium, coarse sand etc. which naturally did not indicate the sand qualities as discussed in para 1.26 and 1.27. The designs, obviously, were based on these vauge terms and it appeared to be one of the main causes of their unsatisfactory performances and early failures.

We Now at some place, sieve tests to determine the quality of sand are being carried out on new wells in this province but still at quite a large number of places the old practice persists. The exploratory tube-well organisation of Government of India, however, carries out the sieve test before a finaldecision on design of screen is taken.

In order to have good design for better performance and to prevent undesired failures, the following tests must be carried out before a well is finally taken up for construction.

(1) Sieve test to determine the physical properties of sand.

(2) Permeability test (discussed in detail in Chapter II) for determining the yield of formation.

(3) Chemical analysis to determine the corroding and incrustating properties of water (discussed in detail in Chapter III).

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C H A P T E R II

G R O U N D   W A T E R   M O V E M E N T
A N D
H Y D R A U L I C   O F   W E L L.

Symbols used in Chapter II

A	=	Cross sectional area.
B	=	" hydraulic resistance" ~~of~~ for motion, head loss per unit discharge.
b	=	thickness of confined sand
C	=	Co-efficient in terms of CQ^2 expressing " well loss"
D	=	Diameter of pipe
d	=	representative grain diameter.
g	=	acceleration due to gravity.
hl	=	head loss
h	=	head above a given datum
k	=	specific permeability
K	=	Co-efficient of permeability
L	=	Length of porous medium
n	=	porosity of sand
Δp	=	Pressure difference
p	=	pressure
Q	=	Well discharge
S	=	Co-efficient of storage
s	=	draw down at a distance x
Sw	=	drawn down at Xw according to theoretical logarithimic distribution
T	=	"Transmissibility" of sand bed = Kb
t	=	time
t*		"inflection time" $= \frac{X^2 S}{4T}$
u	=	$\frac{X^2 S}{4Tt} = \frac{t^*}{t}$ a nondimensional variable
v	=	Velocity of flow
V	=	Volume

V_W	=	Volume of water.
$W(u)$	=	"well function" of u
x	=	raidal distance from the axis of well
Z	=	Elevation
β	=	Aquifer compressibility
μ	=	Viscosity
ρ	=	Fluid density
γ	=	Specific weight of water.

DEFINITIONS OF TERMS USED IN CHAPTER XI

1. Aquifer: It is a geological formation, a part of a formation or a group of formations that will yield significant quantity of water.

2. EFFECTIVE RADIUS OF WELL: It is defined as the distance, measured radially from the axis of the well, at which the theoretical draw-down based on the logarithimic head distribution equals the actual draw down just outside the screen.

3. UNCONFINED AQUIFER: In this aquifer the water table serves as the upper surface of the zone of saturation.

4. CONFINED AQUIFER: It is also known as artesian or pressure aquifer, occurs where ground water is confined under pressure greater than atmospheric by overlying relatively impermeable strata.

5. STANDARD CO-EFFICIENT OF PERMEABILITY- Ks: It is defined as the flow of water at 60^{0} F in gallons per day through a medium having a cross-sectional area of 1 ft^{2} under a hydraulic gradient of 1 ft/ft. It is also sometimes defined as laboratory co-efficient of permeability and its value for most of the natural aquifers ranges from 10 to 5000.

6. STORAGE CO-EFFICIENT-S: It is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface. In most confined aquifers, values fall in the range $0.00005 \leq S \leq 0.005$.

7. CO-EFFICIENT OF TRANSMISSIBILITY- T: It is the product of the aquifer thickness and the co-efficient of permeability (T= Kb, where b is the thickness of aquifer)

GROUND WATER MOVEMENT AND HYDRAULIC OF WELL

5 2.1 The water wells, generally, serve one purpose only and that is to transmit for economical pumping the largest amount of water from the formation in which they are constructed within the limits of well depth, methods of construction and material used.

2.2 There are two major factors which govern the performance of a well. One is the formation in which the well is constructed and the other one is the well structure itself. Both these components have an ability to transmit water. But the hydraulics of structure is quite different from the hydraulic characteristics, of ground water formations.

2.3 The hydraulics of well involves flow:-

(a) in the surrounding aquifer

(b) through the well screen.

(c) Inside the well.

Before going for a costly well scheme, it is essential that a complete knowledge of the hydraulic behaviour of the geological formation and that of well structure is first obtained. If they are not understood correctly before-hand, then it may be possible that the entire scheme may prove a complete failure afterwards.

2.4 DARCY'S LAW - Darcy (1) studied the flow of water through sand beds and reported in 1856 that flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path. This is known as Darcy's law. The statement can be expressed in general terms:-

$$Q = K A \frac{dh}{dL} \qquad \text{..........} \quad (1)$$

or

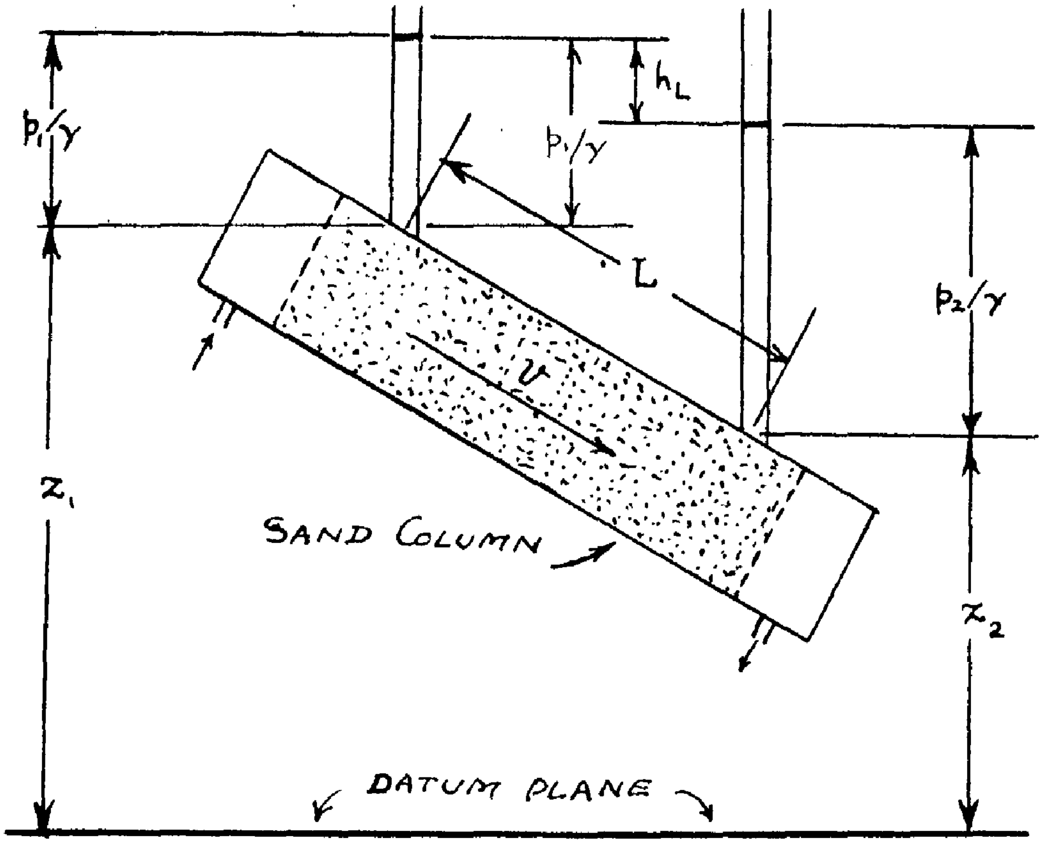


FIG 24

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_L$$

Neglecting velocity head

$$h_L = \left(\frac{p_1}{\gamma} + z_1\right) - \left(\frac{p_2}{\gamma} + z_2\right)$$

According to Darcy

$$Q \sim h_L \quad \text{and} \quad Q \sim \frac{1}{L}$$

$$\therefore Q = K \frac{h_L}{L}.$$

$$\text{also } V = \frac{Q}{A} = K\frac{dh}{dL} \quad \ldots\ldots\ldots \quad (2)$$

where $\frac{dh}{dL}$ is the hydraulic gradient (fig. 24). It will been seen that discharge Q is directly proportional to a constant K known as the co-efficient ofpermeability or the hydraulic conductivity and the hydraulic gradient. In the derination of the above formula it has been assumed that velocity of flow is very low which is generally the case, i.e. ground water movement is very slow.

2.5 RANGE OF DARCY'S LAW: The law applies to laminar flow in porous media where the velocity is very low and is proportional to the first power of hydraulic gradient. Both from theory and experiments it has been found that no lower limit exists for Darcy's law (3) on the contrary, however, an upper limit has been identified by experiments on sand and small spheres (4, 5, 6, 7, 8). This limit can be found by plotting the dimensionless Fanning friction factor f fused in hydraulics, against Reynold's N_R The factor f is defined as

$$f = \frac{d\Delta p}{2\rho L V^2} \quad - - - - - - - - - (3)$$

2.6 From the data plotted from several investigations (fig. 2.6), it is clear that departure from a linear relationship appear when N_R reaches the range between about 1 and 10. For almost all ground waters, the value of $N_R < 1$, therefore, Darcy's law is applicable. Deviation from Darcy's law may be found in rock aquifers, in unconsolidated aquifers with steep hydraulic gradients or in those containing large diameter solution openings.

2.7 Experiments have shown that laminar flow which do not obey the Darcy's law exists in porous media. Each particle of fluid moving through a porous medium follows a continuously varying

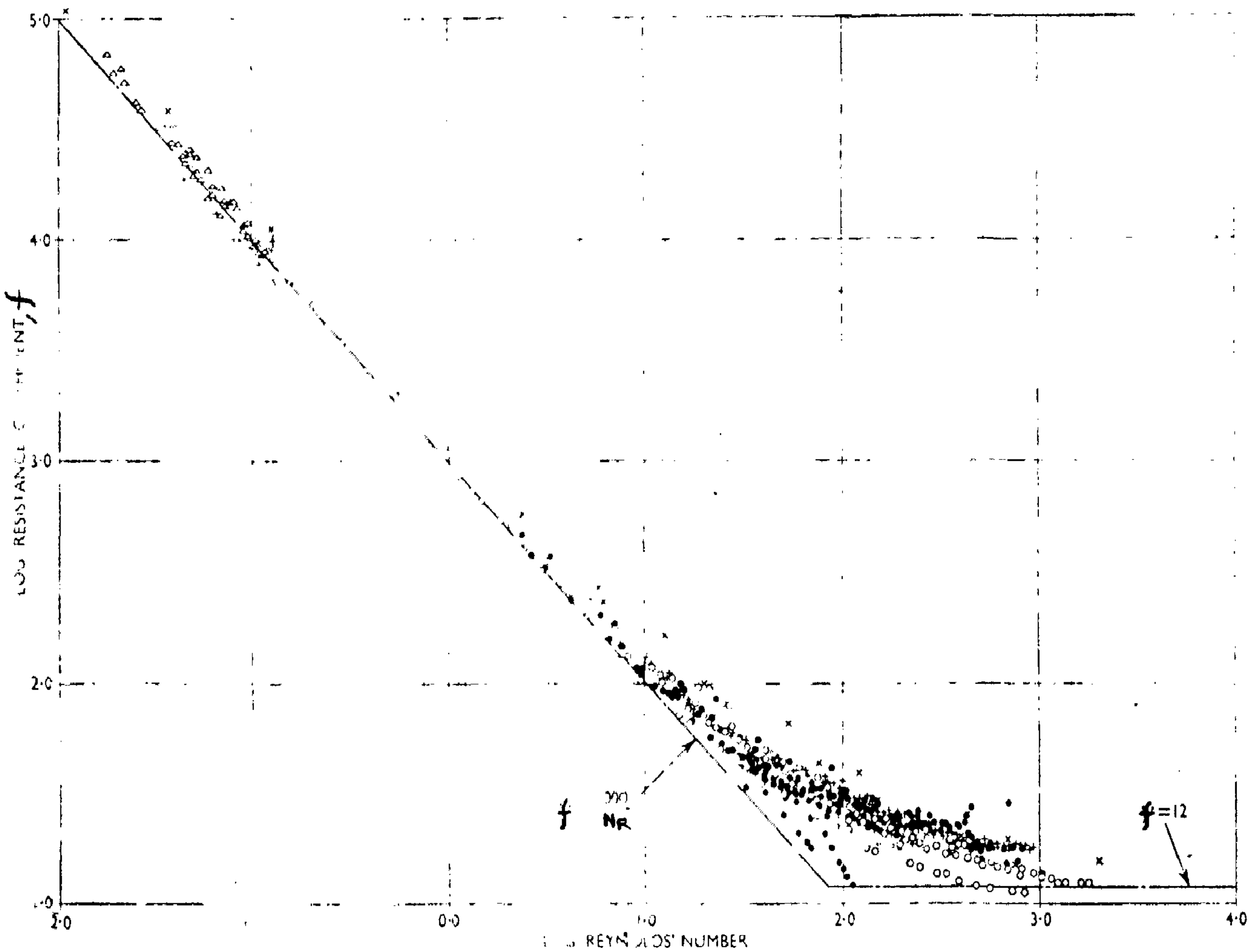


Fig. 26. Curve of Resistance Coefficient plotted against Reynolds Number, for a Granular Bed
Correlated from the data of many workers.

● Burke and Plummer. + Saunders and Ford. Δ Mavis and Wilsey. × Rose. ○ Bakhmeteff and Feodoroff.

accolation (5). At slow rate of flow (near $N_R = 1$ to 10), the inertial forces in this non-uniform flow becomes significant. Darcy's law governs flow only when resistive forces predominate; and when the inertial forces approach the same order of magnitude of the resistive forces, Darcy's law is inapplicable. This transition occurs before and separate from the incidence of turbulance which occur when the value of N_R is 1000 approx. (fig. 2.6). The gradual transition to the turbulant flow depends upon the microstructure of the porous media flow.

2.8 **PERMEABILITY:** Permeability or perviousness of a formation, is its capacity for transmitting water through a given cross-section under a given difference of water pressure per unit of distance. It may vary widely in the same formation depending upon the pressure conditions. It depends upon the properties of a fluid also.

From equation (1) we have co-efficient of permeability

$$K = \frac{Q}{A\,(dh\,/\,dL)} \quad \ldots\ldots\ldots \quad (4)$$

$$= \frac{L^3/T}{L^2\left(\frac{L}{L}\right)} = \frac{L}{T} \quad \text{dimensionally.}$$

This shows that K has the dimension of velocity. Based on Darcy's law Dr. Meinzer of U.S. Geological Survey has standardised the permeability definitions.

2.9 In field terms the co-efficient of permeability Kf is defined as number of gallons of water a day, at 60^0 F that is conducted laterally through each mile of the water bearing bed (measured at right angles to the directions of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient at the field temperature.

2.10 To have a more rational approach to the concept of permeability, the co-efficient is made independent of the fluid properties governing the flow. The properties of fluid involved are:-

(a) μ - expressing the shear reistance.

(b) γ - expressing the driving force of fluid

(c) d - pore diameter which is assumed proportionate to a representative grain diameter d.

The relation can be expressed as

$$k = f(\mu, \gamma, d) \qquad \text{.........(5)}$$

Solving by diemensional analysis we get-

$$k = C \frac{d^2 \gamma}{\mu} \qquad \text{.........(6)}$$

Where C is a dimensionless constant. Because the product Cd^2 is a property of porous medium only, a specific permeability (9, 10) k of the medium may be defined as

$$k = C d^2 \qquad \text{.........(7)}$$

substituting in Darcy's law (equation 1) we get

$$Q = A \frac{k\gamma}{\mu} \frac{dh}{dL} \qquad \text{........(8)}$$

The dimensions of k are $[L^2]$, or area, which can be roughly interpreted as a unique pore area governing the flow. The constant C depends upon the grain diameter, porosity, packing and grain size distribution and shape. The same value of k for different liquids and gases flowing through a given medium (5) indicates the more rational nature of specific permeability.

Equation (8) can now be written as

$$k = \frac{\mu Q/A}{\gamma\,(dh/dL)}$$

Darcy, the practical unit of specific permeability is expressed as-

$$1 \text{ Darcy} = \frac{\dfrac{1 \text{ centipoise} \times 1\ cm^3/\text{Sec.}}{1 \times Cm^2}}{1 \text{ ATMOSPHERE} / 1 \text{ cm}}$$

$$\text{or} \quad 1 \text{ Darcy} = 0.987 \times 10^{-8}\ cm^2$$

$$\text{or} \quad 1 \text{ Darcy} = 1.062 \times 10^{-11}\ ft^2$$

2.11 Many emperical formulae have been established for finding the permeability. Typical of them is the Fair and Hatch permeability formula (11) which was developed from dimensional considerations and verified experimentally.

$$K = \frac{1}{m\left[\frac{(1-\alpha)^2}{\alpha^3}\left(\frac{\theta}{100}\sum\frac{P}{d_m}\right)^2\right]}$$

where α = Porosity

m = Packing factor and the value of which has been found to be 5.

θ = Sand shape factor, varying from 6.0 for spherical grains to 7.7 for angular grains.

P = percentage of sand held between adjacent sieves and

d_m = The geometric mean of the rated sizes of adjacent

The quation is dimensionally correct.

2.12 Permeability of an aqyifer cannot be determined accurately in the laboratory because porosity, packing, grain, orientation etc. are considerably changed than the natural ones.

2.13 Field Measurement of permeability.

The most reliable method for estimating aquifer permeability in by means of pumping tests with wells (12) in these tests the aquifer is not disturbed, the reliability is superior than any other method.

2.14 GROUND WATER FLOW EQUATION.STEADY FLOW.

The equation of continuity for a 3 dismensional flow in rectangular co-ordinates is expressed as

$$\left[\frac{\partial(\rho v_x)}{\partial x} + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z)\right] = -\frac{\partial \rho}{\partial t} \quad - - - - (9A)$$

Where v_x, v_y and v_z are the veolicity components in x, y, z directions respectively and t is the time. For a steady flow $\frac{dp}{dt} = 0$. Therefore, for steady flow, the continuity equation is

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0 \quad - - - - - (9)$$

assuming an incompressible flow i.e. P = Const. If ϕ is the potential function then by definition we have

$$v_x = -\frac{\partial \phi}{\partial x}; \quad v_y = \frac{\partial \phi}{\partial y}; \quad v_z = \frac{\partial \phi}{\partial z} \quad - - - - - (10)$$

Substituting equation (10) in equation (9) we have the Laplace equation

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \quad \ldots\ldots\ldots (11)$$

This Condition ___ also indicates an irrotational flow.

From Darcy's law we get

$$\frac{Q}{A} = K \frac{\partial h}{\partial s} = v$$

Wehere S is the distance along the average direction flow. Conditions when the permeability vary with flow direction is known as anisotropic permeability. Therefore, we can express the component vlocities as

$$v_x = K_x \frac{\partial h}{\partial x} ; \; v_y = K_y \frac{\partial h}{\partial y} ; \; v_z = K_z \frac{\partial h}{\partial z}$$

Where k_x, k_y and k_z are the permeability in x, y, z directions. For simplification assuming isotropic conditions we have $v_x = K\frac{\partial h}{\partial x}$; $v_y = \frac{K \partial h}{\partial y}$; $v_z = K\frac{\partial h}{\partial z}$ ...(12) Comparing equations (10 and (12) we find $\phi = -Kh$ Substituting the value of ϕ in equation (11) we get

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \quad \ldots\ldots\ldots (13)$$

This is the general partial differential equation for steady flow of water in homogeneous and istropic media.

2.15 UNSTEADY FLOW: To derive equation for unsteady flo (13), we have to take into account the storage co-efficient S. For an unconfined aquifer it is defined as specific yield, but for confined aquifer it give the aquifer compressibility β which is defined as

$$\beta \quad -\partial v / v$$

Assuming that compressive force acts in a vertical direction over a large areal extent so that changes in the lateral direction are negligible. When the piezo-metric surface is lowered a unit distance the quantity of water released from the column by the pressure change in S; hence $S = \partial V$. If b is the aquifer thickness then volume of aquifer column is V= 1. b = b. The change in pressure $\partial p = -\gamma(1) = -\gamma$ Substituting these values in equation (14) gives

$$\beta = \frac{S}{b\gamma} \qquad \text{........(15)}$$

Assuming water to be compressible and grains of the media to be rigid, for an elastic material

$$\frac{\partial V}{V} \doteq \frac{\partial \rho}{\rho} \qquad \text{.......(16)}$$

Substituting in equation (M) gives we get

$$\partial \rho = \rho \beta \partial p \qquad \text{.......(17)}$$

Substitution in equation (2A) gives

$$\left[\frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} + \frac{\partial(\rho v_z)}{\partial z} \right] = \frac{\rho s\, dp}{b\gamma\, \partial t} \text{.......(18)}$$

Assuming to be constant and substituting the values of vx, vy and vz from (12) we get -

$$K\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} \right) = \frac{S}{b\gamma} \frac{\partial p}{\partial t} \qquad \text{.......}$$

Rewriting and substituting

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S}{Kb} \frac{\partial h}{\partial t} \qquad \text{.........(19)}$$

Which is the approximate partial differential equation governing the unsteady flow of water in a compressible confined aquifer of uniform thickness b. The corresponding equation for unconfined aquifer has a non-linear from (13) which makes direct solutions impossible. By approximation, however, equation (19) can be applied to unconfined aquifers where variations in the saturated thickness are relatively small.

WATER TABLE

2.16 SIGNIFICANCE: Before tackling any ground water problem, information consérning location, movement, and slope of " water table " is of utmost importance. We must know its depth below the surface, direction and rate of slope and variation in depth that have taken place over various periods of time. The water table is always fluctuating up and down. Its movement tells the story as to the replenishment, the general nature, and the use made of the water bearing formation in which it is found.

2.17 There is a difference in the water table of bodies of free water and bodies of confined water, Water table is the actual level of free ground water, while a pressure surface or the piezometric surface is the actual level either above or below the ground surface to which water under confinment will rise. Both are static levels.

2.18 In order to assertain whether the well has been located in a confined water or a free-water, a few observation holes are drilled around the main well. If on pumping the deep well the water goes down in the observation holes and then all rise to the same level when pumping is stopped, the deep well is in free water. If, however, the water remains stationary in the observation holes, then the deep well is in confined water.

2.19 Throughout the depth of well, there are so many food water into other horizons or rob them. It is therefore doubly important to observe the action of water table at all times where more than one water-bearing strata is topped on a well as is generally the case of state irrigation wells of U.P.

2.20 Before going into the question of locating wells in an area, it is very much beneficial to plot the water table map by putting down a number of test holes to the level of free ground water. The contourss of the map will reveal the general character of a water bearing formation. If the contours are crammed and rise steeply, the formation will be fine, while if the material is coarse, the contours will be further apart and flat. Down the slope of the water table is the general direction of flow. The maps of the pressure surfaces can be made in the similar way.

2.21 As a general rule, water table follows the surface topography without abrupt changes, being nearer the surface in low areas and deeper in high area. On account of their general principles it will nearly always be beneficial to sink test holes in a flat or rolling country in order to locate the deeper and better water formations. It has also been found practically that the water table sloped "with and towards" the main drainage of the area.

2.22 Gradual lowering of water table over a period in a tube-well area indicates excess drawal of ground water. Gaining time of original level after pumping has been stopped indicates quality of permeability of formation. It can also be helpful in determining whether the formation has properly been developed. In short we can very well say that the water table of a deep well works as a stethoscope to ascertain almost all the diseases of the well and its study is extremely important for the survival of a well.

IMPROVED TECHNIQUE FOR LOCATION OF A WELL

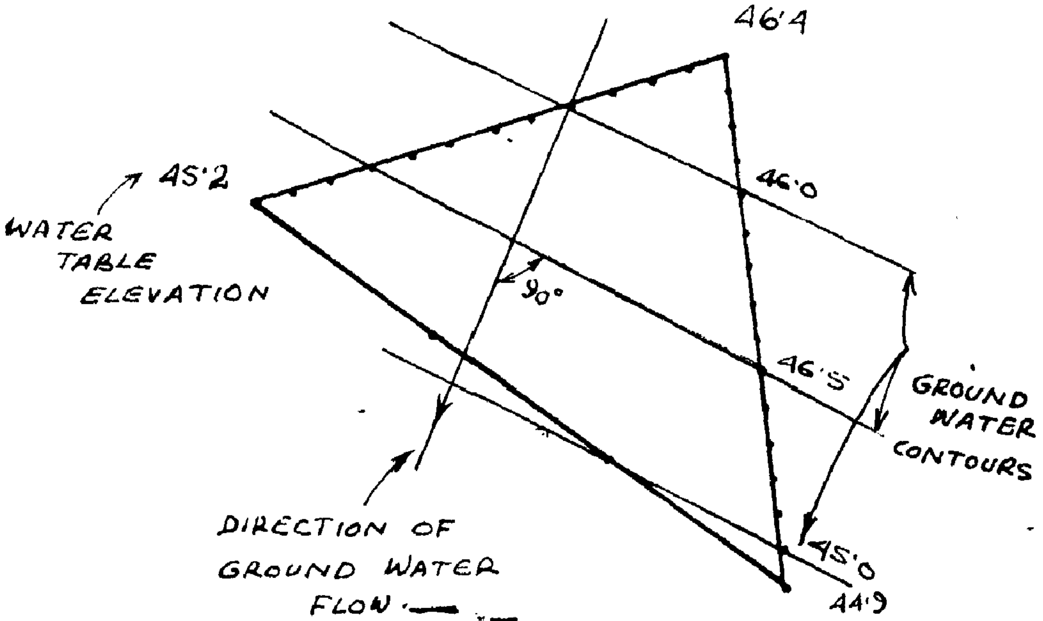


FIG. 2'24

GROUND-WATER CONTOURS AND FLOW DIRECTION FROM WATER TABLE ELEVATION IN THREE WELLS unconfined aquifer, it becomes the bounding surface. The energy head H_e or fluid potential at any point on the water table is approximately (fig. 2.4)

$$h_e = \frac{p}{\gamma} + Z$$

If the atmospheric pressure reference be taken as zero, then $p = 0$

$$\therefore \quad h_e = Z.$$

therefore under steady state conditions, the elevation at any point on the water table equals the energy head and, as a consequence stream lines be perpendicular to water table contours.

2.24 With the help of only three ground water elevations known from wells, ground water contours and flow direction is determined as shown (fig. 2.24). After drawing the water contours, stream lines are sketched perpendicular to contours, showing direction of flow. Proceeding in this way, the map of ground water elevation and its stream lines is prepared for the area in which wells are to be located (fig. 2.25).

2.25 Considering any two stream lines on the map and taking into account the fact that there is no flow across the stream lines, the flow at section 1 and 2 in (fig. 2.25) equals.

$$Q = A_1 v_1 = A_2 v_2 \quad \ldots\ldots \quad (20)$$

Where A is the saturated area perpendicular to the flow. From Darcy's Law,

$$A_1 \; K_1 \; i_1 = A_2 \; K_2 \; i_2 \quad \ldots\ldots \quad (21)$$

Where $i = \frac{dh}{ds}$ the hydraulic gradient

Re-arranging equation (21) we have-

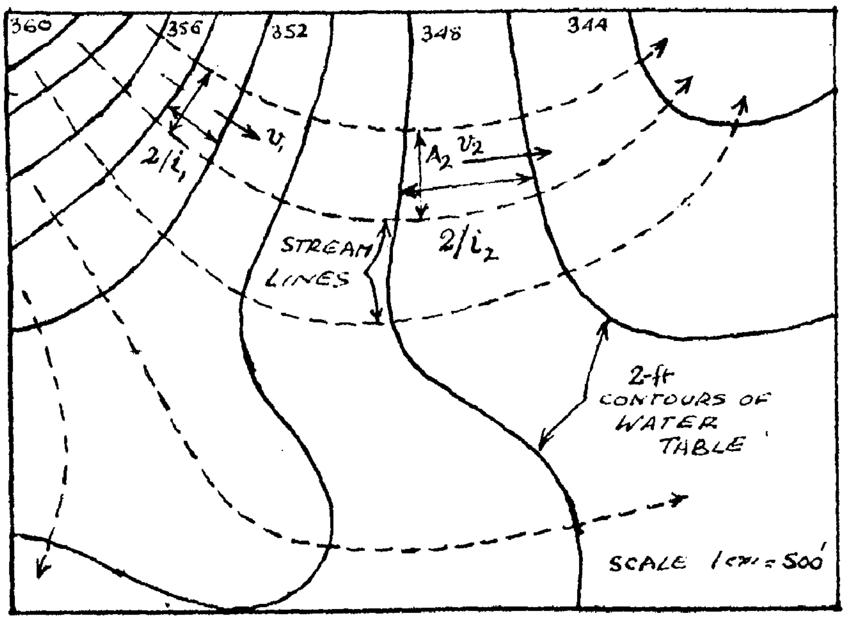


FIG 2·25

WATER-TABLE MAP SHOWING STREAM LINES

$$\frac{K_1}{K_2} = \frac{A_2 i_2}{A_1 i_1} \quad \ldots\ldots\ldots (22)$$

The ratio $\frac{A2}{A1}$ can be ascertained from the distance between flow lines at the two sections for an unconfined aquifer if the difference in elevation of the water table is small compared to the saturated aquifer thickness, or for a confined aquifer of uniform thickness, Similarly, i_2/i_1 can be estimated from the respective contour spacings.

If the stream lines are nearly parallel then equation (22) becomes

$$\frac{K_1}{K_2} = \frac{i_2}{i_1} \quad \ldots\ldots\ldots (23)$$

2.26 This equation shows that for an area of uniform ground water flow, that portion having wide contour spacings will have high permeabilities than those with narrow spacings, Therefore, prospects for a good-yielding well are better near Secion 2 than 1.

2.27 Thus we see that ground water contour map becomes a powerful tool in the hands of an engineer for selecting the areas of favourable permeability and the best possible source of ground water supply.

2.28 As for as the author knows, not much attention is being paid to the water table contour map while locating state wells. Generally, these are located at the highest spot of the area which is to be irrigated by the well irrespective of water table study. Area to be irrigated by one well of 1.5 cusecs is about 1000 acres. Besides losing the advantage of the best possible site, there is sometimes economical disadvantages too in choosing the site at the highest place, which is done because of the gravity flow irrigation method. In this vast area, the ground contours vary a lot and therefore the water table contours will also vary (para2.21).

2.29 Suppose there is a difference of 3 ft. in the ground levels of the highest spot of the area and the spot which will be most suitable as revealed by the water table contour map. If the difference in the water tables of the two spots is only 1.5 ft., then the head against which the pump will work if located at the lower spot to raise the water at the highest level of the ground will be 1.5 ft. less, than if the pump is located directly at the highest spot.

Thus for a discharge of 33,000 g.p.h. and pump efficiency of 60%, the saving in the pumping cost will be as calculated below:-

$$W.H.P. = \frac{33,000 \times 10 \times 1.5}{550 \times 60 \times 60}$$

$$= \frac{66}{264} = \frac{66}{264}$$

$$H.P. = \frac{66}{264} \times \frac{100}{60}$$ (pumping η = 60%).

$$= 0.42 \text{ H.P.}$$

Fixed electricity charges for
0.42 H.P. @ Rs. 150.0/H.P. per
year = Rs. 63.0

Wells are running for 5000 hours approx. per year therefore KW Hr. per year will be

$$\frac{0.42 \times 746 \times 5000}{1000} = 746 \times 21 \text{ K.W. Hr.}$$

$$= 1566.6 \text{ K.W. Hr.}$$

Cost of electricity @ 5.5 n.P. /KW.Hr.

Then annual saving $= \frac{1566.6 \times 5.5}{100} + 63$

Rs. 149.3

Say Rs. = 150.00 per well.

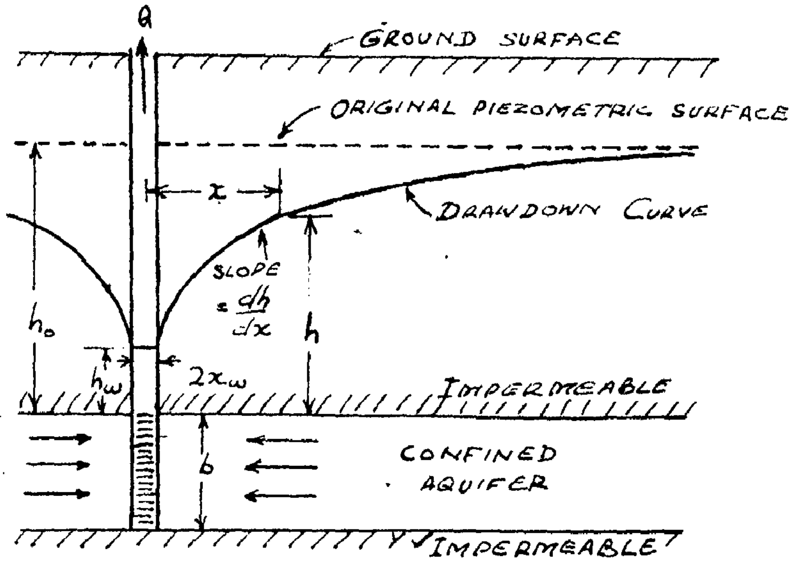


FIG. 2'32.

RADIAL FLOW TO A WELL PENETRATING EXTENSIVE CONFINED AQUIFER

2.30 The location of well at a depression point means making the water courses in filling and more expenditure on maintenance. Author feels that the extra maintenance expenditure on guls in small extra filling portion will not be much and thus net saving of about Rs.125/- per well will acrue by paying slight attention on water table while locating the well. However, it needs a close check before taking final decision.

Also in an area where 300 wells are located and if the saving is 0.5 H.P. per well for 100 wells on an average, then the extra H.P. released for other purposes will be 50 H.P. besides an operational saving of Rs. 6000/- approx.

2.31 The above calculations have been made on the assumption that draw down in both the cases will remain the same. However, the permeability at the place where the stream lines are placed further apart will be good which will result into a lesser draw-down and consequently in a still better economy.

RELATION BETWEEN THE WELL DISCHARGE TO DRAW-DOWN

2.32 Steady Radial flow to a well in confined aquifer:

When a well is pumped, the water is removed from the aquifer surrounding the well and the piezometric surface is lowered and in three dimensions assumes a conic shape and is known as the cone of depression. Outer limit of the cone defines the area of influence of the well. Dupuit derived his formula for discharge from a well assuming -

(i) the flow to be horizontal and uniform everywhere in a vertifical section.

(ii) the velocity of the flow to be proportional to the tangent of the hydraulic gradient.

origin, the well discharge Q at any distance x for steady radial flow (figure 2.32) equals

$$Q = Av = 2\pi x bk \frac{dh}{dx} \quad \ldots\ldots\ldots \quad (24)$$

Re-arranging $\quad Q\frac{dx}{x} = 2\pi bk\, dh$

Integrating $\quad Q \log X = 2\pi bkh + C \ldots \quad (25)$

Substituting the boundry conditions at the well,

$h = h_w$ and $x = X_w$

$\therefore C = Q \log X_w - 2\pi bkh_w$

Substituting in equation (25) and solving for Q we get

$$Q = 2\pi kb \frac{h-h_w}{\log\frac{x}{x_w}} \quad \ldots\ldots\ldots \quad (26)$$

2.33 Relation shows that h increases indefinitely with increasing x. But the maximum h is the initial uniform head ho. Thus, from a theoretical aspect, steady radial flow in extensive confined aquifer does not exist. However, practically h approaches ho with distance from well. For a radius of influence $x = x_0$ and $h = h_0$ we get $\therefore$ $Q = 2\pi kb \frac{h_0-h_w}{\log x_0/x_w}$

Eliminating Q from equation 26 we get draw down

$$h-h_w = (h_0-h_w)\frac{\log (x/x_w)}{\log (x_0/x_w)}.$$

2.34 Equation (26) is known as Thiem (2) equation and enables the permeability to be determined from a pumped well. The co-efficient of permeability is given by

$K = \frac{Q}{\ldots}$ ~~log x2~~ $\quad K = \frac{Q}{[illegible]} \log\frac{x_2}{x_1}$

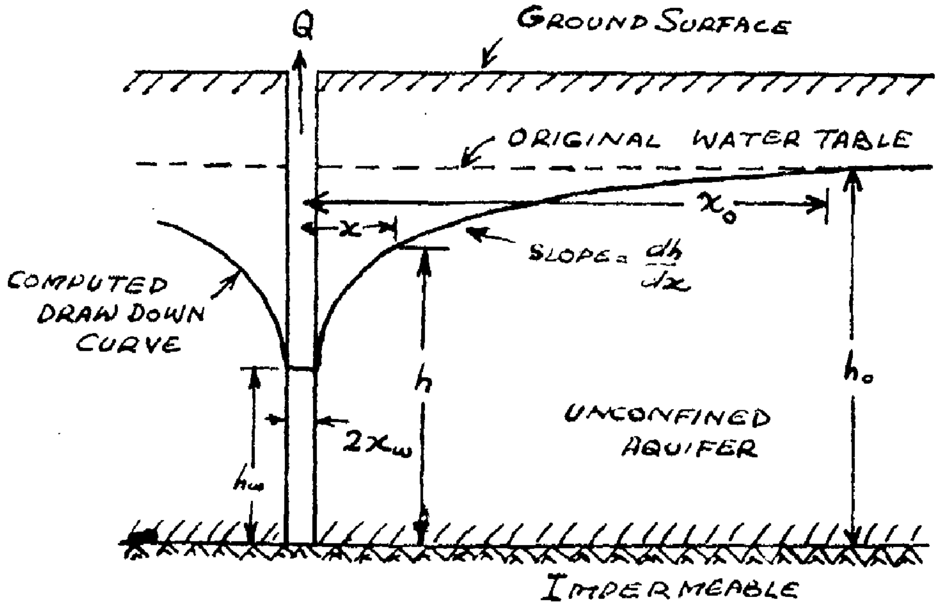


FIG. 2'35

RADIAL FLOW TO A WELL PENETRATING AN UNCONFINED AQUIFER.

Where X_1 X_2 h_1 & h_2 are the distances from the well centre and the heads of the respective observation wells.

2.35 <u>Steady radial flow to a well in an unconfined aquifer:</u> Fig. 2.35 shows the well completely penetrating the aquifer to the horizontal base and a concentring boundry of constant head surrounds the well. The well discharge is -

$$Q = 2 \pi x k h \frac{dh}{dx}$$

Integrating between the limits $h=h_w$ at $x = x_w$ and $h = ho$ at $x = x0$, yields

$$Q = \frac{\pi k (ho^2 - hw^2)}{\log (xo/x_w)} \qquad \ldots\ldots \quad (27)$$

Because of large vertical flow components, this equation fails to describe accurately the draw-down curve near the well, but Q is determined sufficiently accurate. The value of xo ranges from 500 to 1000 feet.

2.36 <u>WELL LOSSES.</u> Apart from the draw down the following losses also occur in a well:

(a) loss caused by flow through well screen.

(b) loss due to flow inside the pipe to pump intake

Since the loss in the pipe occurs due to turbulent flow, it may be taken as proportional to Q^n, where n is a constant greater than one. Previously a value n=2 was assumed reasonably satisfactory (16) but latter experiments by Rorabough (17) showed that n may devide significantly from 2 and should be computed from step draw down pumping tests. The value of n will very from well to well due to different conditions. But the major part of the loss of head, occurs in the formation, where the energy expanded in over-

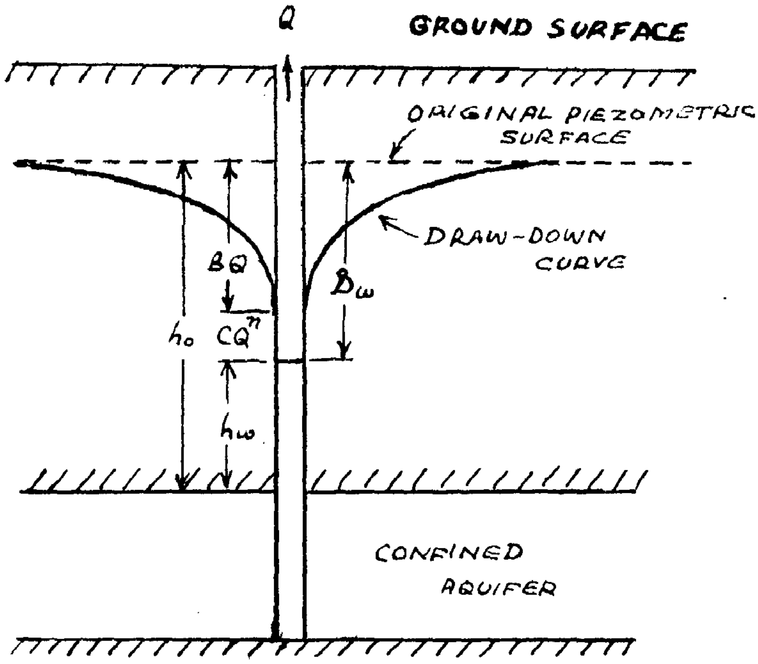


FIG. 2·37

WELL LOSS CQ^n TO DRAWDOWN IN A WELL PENETRATING A CONFINED AQUIFER moving water is directly proportional to that rate of motion.

2.37 From equation (26) of a confined aquifer, re-arranging we get, taking into account the well losses as described in para 2.33, the total draw down

$$D_w = h_o - h_w = \frac{Q}{2\pi Kb} \log \frac{x_o}{x_w} + CQ^n \quad \ldots\ldots (28)$$

Where C is a constant and its value depends upon the radius, construction and condition of the well.

$$\text{Let } B = \frac{\log (x_o/x_w)}{2\pi Kb} = \frac{\log (x_o/x_w)}{2\pi T}$$

then $S_{w\,draw} = BQ + CQ^n$, (See fig. 2.37) ..... (29)

i.e. total drawn sw consists of aquifer loss BQ and well loss CQ^n. Factor B is defined as the resistance of the formation.

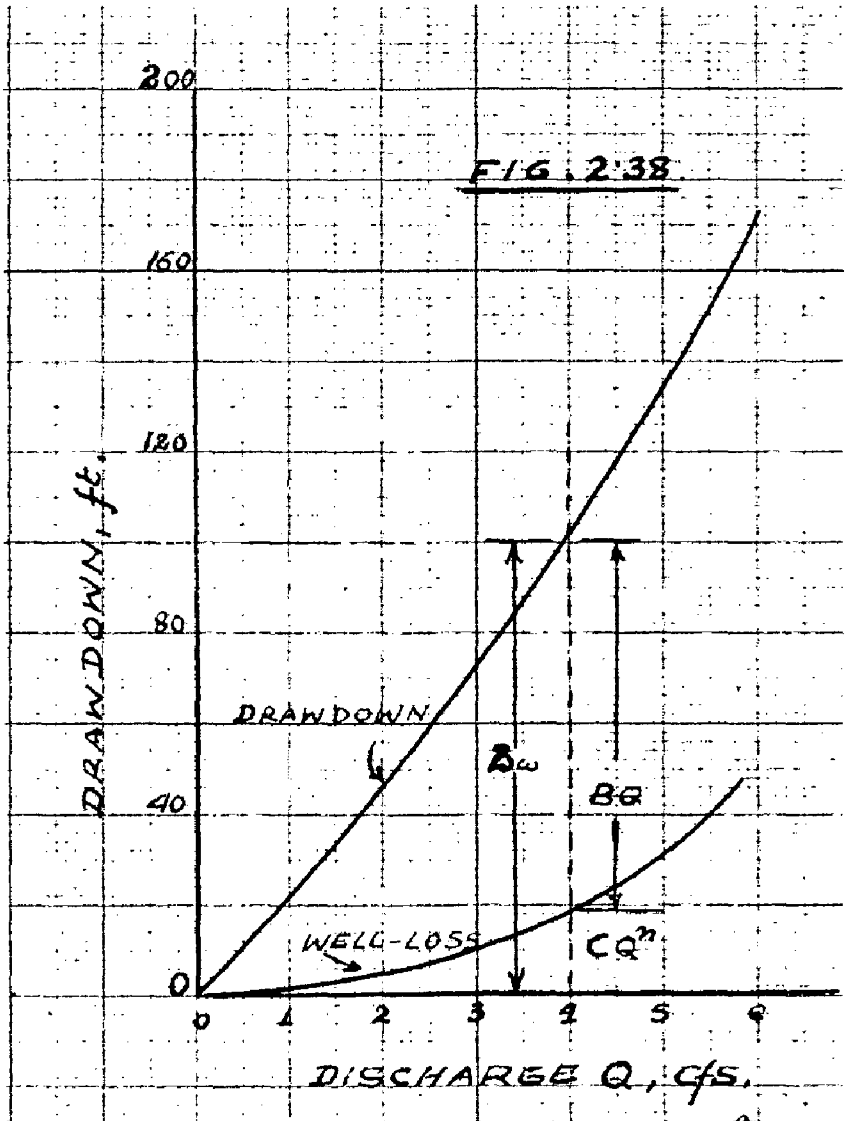
2.38 In order to minimise the losses, it is necessary that the velocity into and within the wells are kept to aminimum. If the well radius is doubled, this will double the intake area and will rduce the entrance velocity to almost half, and (if n = 2) cuts the fricitional loss to less than a third. For axial flow within the pipe, the area is increased four times which will reduce the loss to a greater extent. Graph in fig. 2.38 illustrate the variation of well loss with discharge (17), Well loss due to axial flow is much higher than the loss due to water entering in the well (18).

2.39 Specific capacity of a well is defined as the ratio of discharge to drawn-down.

$$\text{Specific capacity} = \frac{Q}{sw} = \frac{1}{B + CQ^{n-1}}$$

$$\text{or } \frac{Q}{sw} = \frac{1}{B + CQ} \quad \text{if } n = 2$$

This relation shows that specific capacity of a well



VARIATION OF TOTAL DRAW-DOWN S_w, AQUIFER LOSS BQ AND WELL LOSS CQ^n

(Ref - 17)

decreases with increase of flow and is not constant.

2.40 Non-Steady flow to a well in a confined aquifer:

2.40 Consider a cylindrical shell of height b, inner radius x and outer radius x + dx. By principle of continuity the outward flow from the shell through its inner cylindrical surface

$$= 2\pi x T \left(\frac{\partial h}{\partial x}\right)$$

Similarly outward flow through the outer cylinder surface =

$$= 2\pi T (x + dx)\left(\frac{\partial h}{\partial x} + \frac{\partial^2 h}{\partial x^2}\,dx\right)$$

The sum of these two must be equal to the time rate of decrease of the enclosed volume of water between two impervious bounding planes.

The time rate of decrease of the enclosed volume of water $= 2\pi x\,dx\,S\,\frac{\partial h}{\partial t}$

Where S is the co-efficient of storage (25,26)

Therefore:

$$-2\pi x T\left(\frac{\partial h}{\partial x}\right) + 2\pi T (x + dx)\left(\frac{\partial h}{\partial x} + \frac{\partial^2 h}{\partial x^2}\,dx\right) = 2\pi x\,dx\,S\,\frac{\partial h}{\partial t}$$

Simplifying we have

$$\frac{\partial^2 h}{\partial x^2} + \frac{1}{x}\frac{\partial h}{\partial x} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad \text{.........} \quad (30)$$

The condition for a correct solution of this differential equation are:-

$s = h_0 - h = 0$, for $t \leq 0$ .... (a)

Limit $\lim_{x \to \infty} s = 0$ for $t > 0$ .... (b)

Limit $\lim_{x \to 0}\left(x \frac{\partial s}{\partial x}\right) = -\frac{Q}{2\pi T}$ for $t > 0$ .... (c)

Theis (27) assuming an analogy between the ground differential equation (30) and gave the solution.

$$h_o - h = S = \frac{Q}{4\pi T}\int_{\frac{x^2 S}{4Tt}}^{\alpha} \frac{e^{-u}\,du}{u} \quad \ldots\ldots\ldots (31)$$

This integral is known as exponential integral.

The solution for this equation is represented by the following expanded convergent series

$$S = \frac{Q}{4\pi T}\left(-0.5772 - \log_e u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \right) \quad \ldots\ldots\ldots (33)$$

where $u = \frac{t^{\circ}}{t} = \frac{x^2 S}{4Tt}$

or we can write

$s = \frac{Q}{4\pi T}$ W (u) where ....(34)

Q = well discharge in cusecs

T = Co-efficient of transmissibility

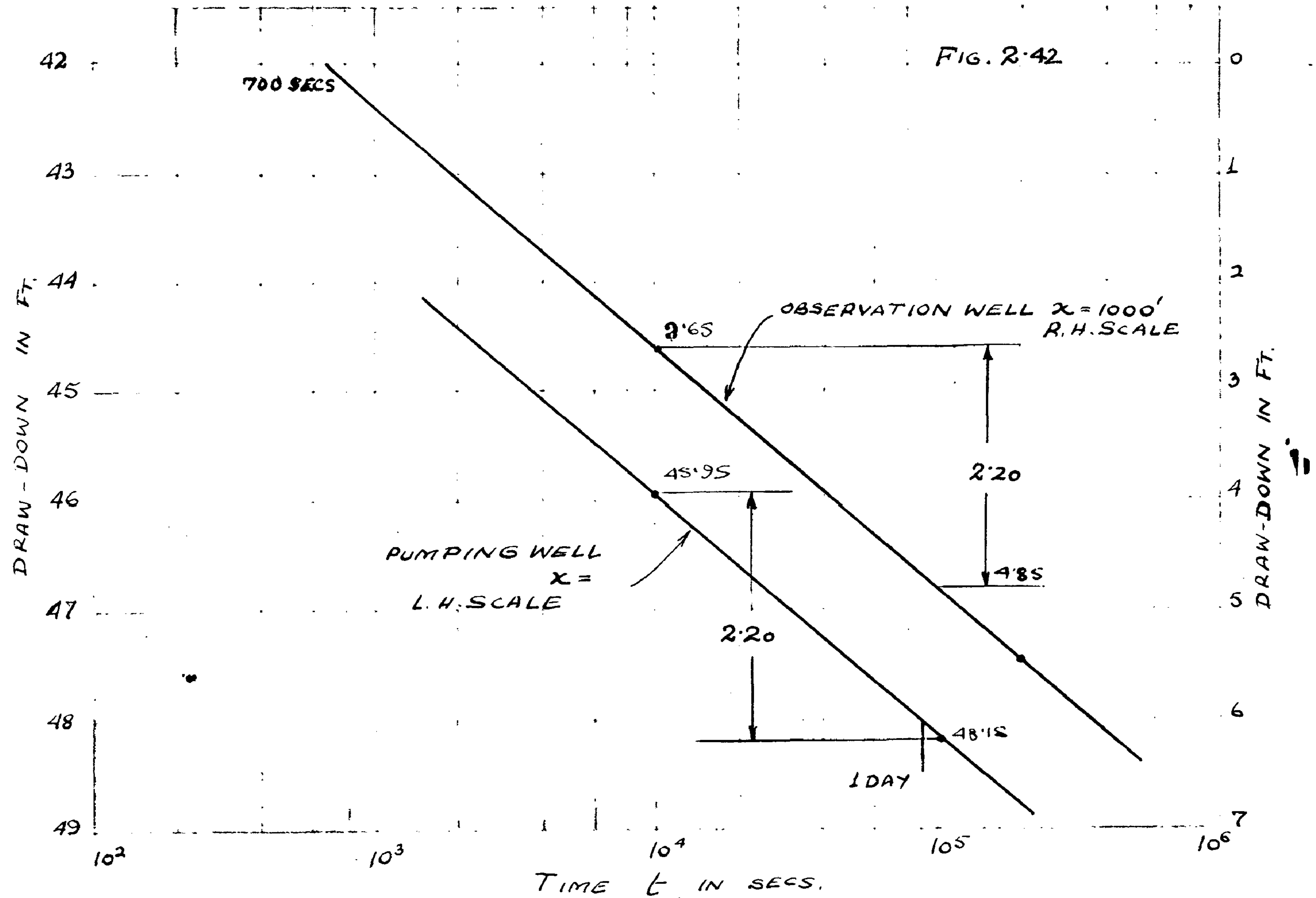
W = exponential integrale known as well function

u = the argument and is given by

$$\frac{x^2 S}{4Tt}$$

2.41 A non-dimension plotting of equation (33) or equation (34) shows that draw down at a given distance from the well increases very slowly at first and reaches a maximum rate of increase at $t/t^{\circ} = 1$ and this is the point of inflection time. t° is called is called the inflection time.

A plot of equation (34) on a semi-logarithimic paper shows that value of function W(u) tends to become a straight line



DATA OF A DRAW-DOWN TEST OF PUMPING AND OBSEVATION WELL FOR FINDING T, S, AND WELL LOSS.

given approximately by the first two items in equation (33) and the other terms become negligible.

$$\therefore \quad s = \frac{Q}{4\pi T}\left(\log_e \frac{t}{t_x} - 0.5772\right) \ldots\ldots\ldots (35)$$

Therefore, from equation (29) the total draw down in the well can be expressed as

$$s_w = \frac{Q}{4\pi T}\left(\log_e \frac{t}{t_w} - 0.5772\right) + CQ^2 \ldots \quad (36)$$

Where $t_w = x_w^2 \frac{S}{4T}$, X_w being the effective radius of the well. From a draw down test, the line fitting the draw down test data enables the formation constant to be computed. Rapid solutions are obtained from

$$T = \frac{2.30Q}{4\pi(s_2 - s_1)} \ldots\ldots\ldots (37)$$

or $T = \frac{2.30Q}{4\pi\Delta h}$ and

$$S = \frac{2.25\,Tt}{X^2} \ldots\ldots\ldots (38)$$

Assuming that-

i. effective well radius is equal to nominal well radius.

ii. The value of S calculated from equation (38) holds within the immediate vicinity of the well.

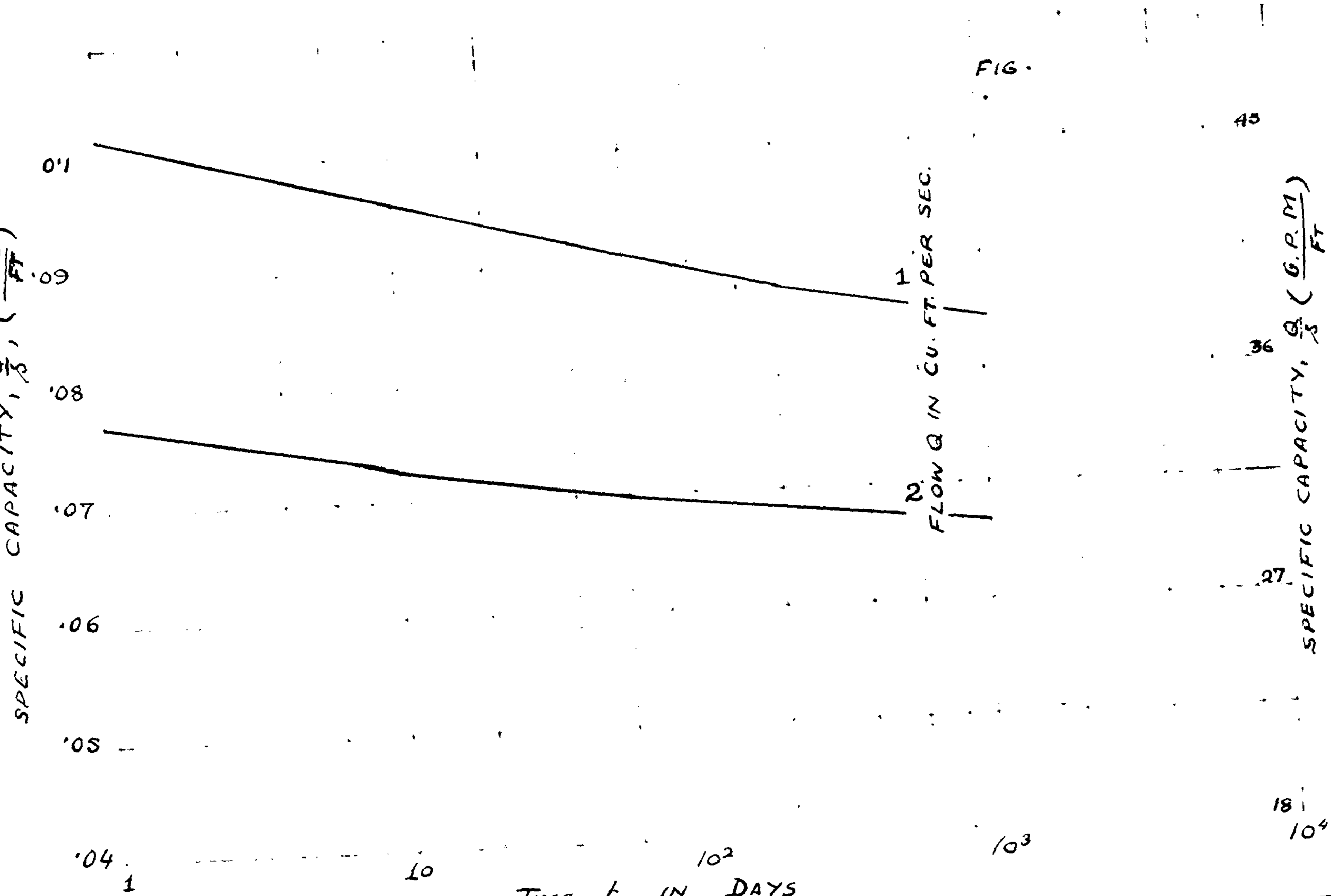
holds

2.42 METHOD FOR SEPARATING THE WELL LOSSES

From equation (36) we have -

$$s_w = \frac{Q}{4\pi T}\left(2.303 \log_{10} \frac{4\,Tt}{r_w^2\,S} - 0.5772\right) + CQ^2$$

FIG.



VARIATION OF SP. CAPACITY OF WELL WITH DISCHARGE AND TIME
(Ref. JACOB)

Fig. 2.42 shws a plot of an observal well dato of draw down and time. The discharge of the main well 6" dia. = 1.5 cusec (normal discharge of state well). The distance of the observation well from the main discharge well = 1000 ft.

From the graph it is seen that change in draw down over one log cycle is 2.20 ft. Therefore substituting in equation (37) we have

$$T = \frac{2.30 \times 1.5}{4 \times \pi \times 2.20} = 0.12 \text{ sq. ft. per sec.}$$

The intercept of the line for zero drawn down is 700 secs. Therefore from equation (38)

$$S = \frac{2.25 \times 0.12 \times 700}{10^6}$$

$$= .00019$$

The value of fraction $\frac{4Tt}{X_v^2 S}$ for one day i.e. 86,400 sec

$$= \frac{4 \times 0.12 \times 86,400}{.00019 \times 0.25}$$

$$= 8.7 \times 10^8$$

$$\therefore \log_{10} \frac{4Tt}{X_v^2 S} = \log_{10} 8.7 \times 10^8 = 9.4$$

Substituting in equation (36) we get

$$48 = \frac{1.5}{4 \times \pi \times 0.12} \times (2.303 \times 9.4 - 0.58) + CQ^2$$

$$= \frac{1.5 \times 20}{4 \times 3.14 \times 0.12} + CQ^2$$

$$= 20 + CQ^2$$

or $CQ^2 = 48 - 20 = 28$

or $C \times 2.25 = 28$ or

$$C = 12.4 \quad \left(\frac{Sec^2}{Ft^5}\right)$$

2.43 Calculations of the above para show that BQ was 20' after 24 hours of continuous pumping. The observed draw-down was 48' and CQ^2 well losses were = 28.5'. In the example solved it was assumed that effective radius of the well was the same as that of screen but in case of gravel pack wells, the effective radius will be considerably be changed and the draw-down will be somewhat less due to decreased head loss.

2.44 Jacob (16) showed that by the help of a multiple drawn down test, the effective radius can be calculated from equation (36) and can be given as

$$Rw^2 = 2.25 \frac{Tt}{S} \qquad \ldots\ldots\ (39)$$

2.45 If the storage coefficient and transmisibility of the bed and effective radius of the well are determined, it is possible to compute the resistance B, at any time, knowing the factor C, it is possible to compute the well loss. Combining the two, the total draw-don in the pumping well may be determined for any time and for any pumping rate.

2.46 APPLICATION OF DRAW DOWN TEST:

By this method it is possible during the life of a well, to determine both the components of its specific draw-down facilitating -

(1) recognition of encrustation of the screen or sand

packing of the gravel well due to which yield from the well falls.

(2) evaluation of effectiveness of gravel packing and various development operations practiced in well construction.

(3) prediction of the trend of pumping levels with time and therefore proper selection of pump so as to give optimum performance during the life of the well.

(4) Knowledge gained by such tests in an area will help in the proper gravel packing and screen opening for maximum well efficiency.

SUMMARY:

(1.) From the survey of wells it was found that the state wells are generally located at places where it is most convenient to have gravity flow irrigation. No study of water table contours was made. In fact, at present also no such study is being made. From discussions of paras 2.19 to 2.21 it is clear that in order to locate efficient and economic wells in some particular area, a prior study of water table contour and ground contour is essential. ~~A map having~~

A. A map having such contours will immediately reveal that crammed and steeply rising water table contours indicate a fine formation which may not be much favourable for well construction.

B. Further apart and flat contours show a coarse formation with better permeability (refer para 2.24 to 2.26) and wells should preferable be located at such places.

C. A study of water table will sometimes result in saving of operational cost as detailed in paras 2.28 to 2.30.

2. After a well has been constructed, a draw-down test (refer paras 2.36 to 2.46) must be carried out. Draw down test at present being done on state wells to find out discharge per foot of depression do not serve any useful purpose. This test will be most helpful and is recommended for separating the two losses so as to ascertain the source of any trouble in future by a subsequent draw down test. The test will help in taking remedial measures as to prevent ulitmate failure (para 2.40 to 2.42)

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CHAPTER --- III

WELL SCREENS

D = Diameter of the well screen.

Fy = Difference in momentum.

g = Acceleration due to gravity.

hpz = Piezo metric head inside the well screen.

Δhpz = Difference in piezometric head between the inside and the outside of a well screen.

$\Delta h'pz$ = Difference in piezometric head between the inside and the outside of a well screen at the end through which no flow passes.

k = Roughness factor for the inside walls of the well screen.

L = Length of the paforated Section of the well screen.

P = Hydrostatic pressure.

ΔP = Difference in pressure between the inside and outside of a the well screen at a point of the well screen.

Q = Quantity of flow, parallel to the screen axis, past a given section inside the well screen.

V = Average velocity parallel to the longitudinal axis inside a well screen.

v = Velocity of flow through the opendings.

Z = Distance from a datum.

γ = Specific weight.

μ = Co-efficient of dynamic viscosity.

ρ = Density.

****

SYMBOLS USED IN CHAPTER III

A = Cross-Sectional Area.

A_p = Percentage of total area of a well screen that is open area.

C = Co-efficient defined by equation.

C_c = Co-efficient of centraction.

C_q = Co-efficient of discharge.

C_s = Well screen coefficient depending upon the screen and the gravel envelope.

D = Diameter of the well screen.

F_y = Difference in momentum.

g = Acceleration due to gravity.

h_{pz} = Piezo metric head inside the well screen.

Δh_{pz} = Difference in piezometric head between the inside and the outside of a well screen.

$\Delta h'_{pz}$ = Difference in piezometric head between the inside and the outside of a well screen at the end through which no flow passes.

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γ = Specific weight.

μ = Co-efficient of dynamic viscosity.

ρ = Density.

****

WELL SCREENS:

3.1. GENERAL with the rapid agricultural and industrial growth in the country in the subsequent plans, it is felt that there will be acute shortage of water which will have to be met by Tubewell supply. Hundreds of crores of rupees will be spent on sinking of tube-wells. To utilise this large amount of money efficiently and economically, it is necessary that well structure be designed scientifically so that they may be efficient and long lasting.

3.2. The yield from a well depends upon:-

I. Characteristics of the underground Reservoir, which can not be tempered with.

II. Well structure and the pumping efficiency upon which depends magnitude of draw-down and operational cost.

The factors as stated in para 3.2. can be manuplated to get best advantage from a well system. As such, modern researches are largely directed to establish better design criteria and developments of well structure. These engineering structures are governed by certain theoretical principles. If these principles are observed conspicuously, an efficient and economical well structure will result.

3.3. One of the most important component of well structure is the well screen. The selection of proper well screen to satisfy the specific demands at site is both important and difficult. The well screens have come into prominence in the last seventyfive years or so. Previously, any thing which kept sand out of the well was regarded and used as screen. As a result the first users called them strainers. But the present day knowledge tells that a well screen is not a well strainer in any sense of the word.

3.4. The basic requirements of an efficient and good well screen are:

I. It should provide minimum resistance to flow of water into well. That is transmitting capacity should be high with minimum head loss.

II. It should prevent undesirable sand movement into the well.

III. It should be strong enough as not to callapse.

IV. It should be resistant to corrosion and deterioration.

V. Its dimensions should be economical.

3.5. To have a well designed and good screen, it is not possible that every aspect of it should have its maximum efficiency, and, therefore, a compromise is necessary in between the several desirable characteristics which must be evaluated before hand for the particular field conditions.

3.6. The discussion on well screen in this chapter has, therefore, been divided into five sections according to the items given in para 3.4. dealing with the influence of these factors on well design and its life. As discussed in the previous chapter the ground formation has an important part in the design of well screen. Importance of sand tests can not be over emphasized. As such typical sand analysis of about a dozen wells of various districts have been given as sample in appendix 'C'.

C H A P T E R - III

S E C T I O N - I

THEORETICAL DEVELOPMENT FOR MINIMUM HEAD LOSS IN WELL SCREENS.

THEORETICAL DEVELOPMENT FOR MINIMUM HEAD LOSS IN WELL SCREENS

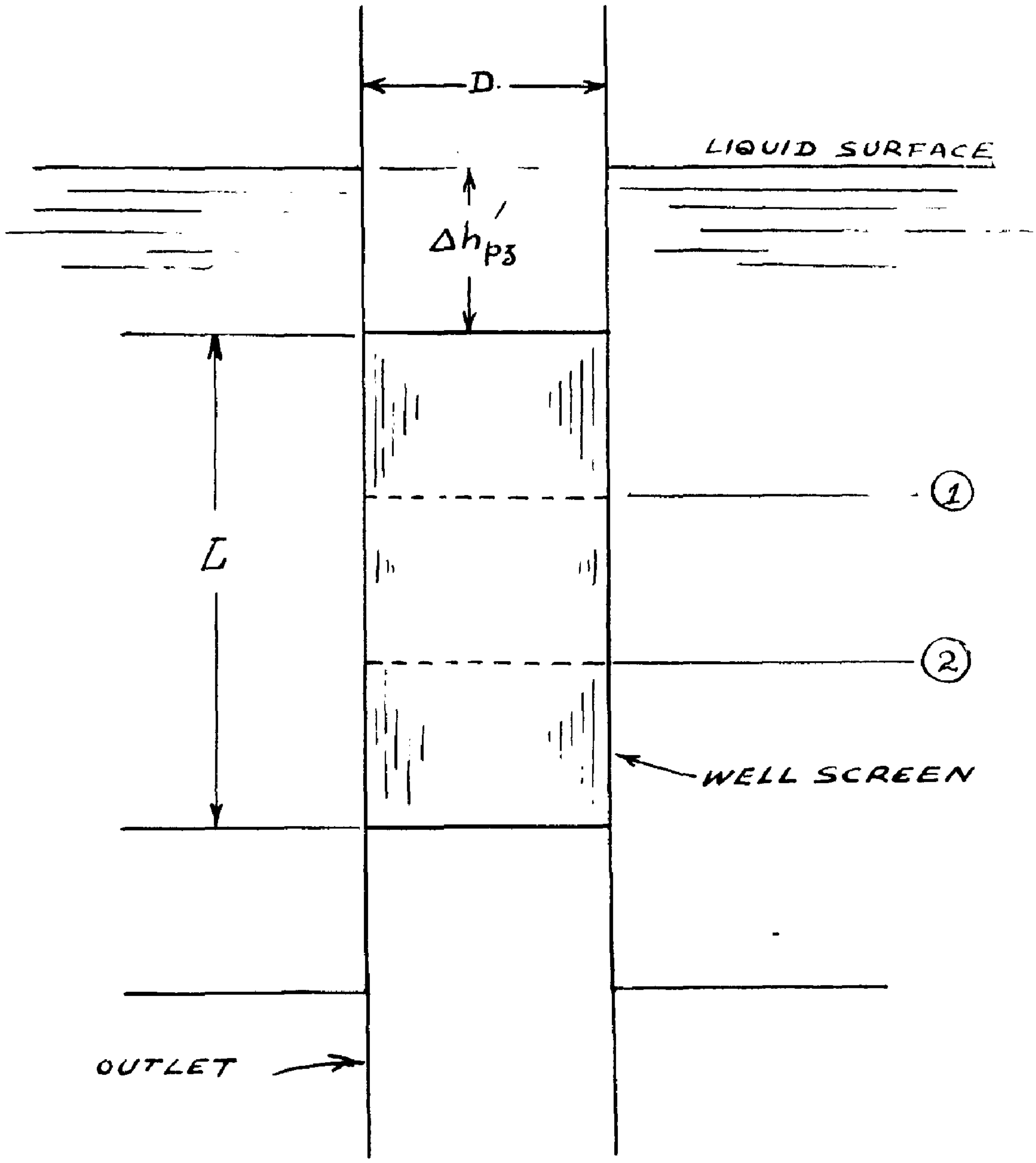
3.7. The flow through and into the well screen can be imagined as water flowing through a series of orifices openings and then flowing into a pipe manifold moving along the axis of the screen. As the water enters the screen, a conversion of the potential energy to kinetic energy takes place and the jet is formed. A dissipation of the jet energy, which can be assumed to be complete, then occurs. That is, the kinetic energy of the jet is not recovered as either potential or kinetic energy. The water then accelerates in a direction parallel to the centre line of the screen.

3.8. In figures 3.8, a well screen of length L and of diameter D is placed submerged in a liquid. The water enters into the screen through its openings and flow out axially with a velocity V. The top of the screen is under a head $\Delta h'_{pz}$.

3.9. As a first approach to the solution, considering the screen surrounded by a liquid only, the loss of head caused by flow through a screen will depend upon the characteristics of screen geometry, the fluid and the flow. The most important variables influencing the flow are:-

1. Screen length, L
2. Screen diameter D
3. The percentage of open area, Ap.
4. The co-efficient of contraction for the opening Cc.
5. The internal roughness of the screen Z.
6. The difference in pressure between the inside and outside of the screen - Δp.
7. The velocity of liquid in the well screen V.

FIG. 3.8



8. The mass density of the fluid, ρ.

9. The co-efficient of dynamic viscosity, μ

3.10. The above variables can be arranged in the following relationship:-

$$f\ (L, D, \Delta p, Z, \rho, \mu, V, Ap, C_c) = 0. \text{-(31)}$$

Taking D, ρ, and V as repeating variables and solving by dimensional analysis we get the function:-

$$f_2\left(\frac{L}{D}, \frac{Z}{D}, Ap, C_c, \frac{\Delta p}{\rho V^2}, \frac{V D \rho}{\mu}\right) = 0 \text{-(32)}$$

The parameter $\frac{\Delta p}{\rho V^2}$ can be written as $\frac{\Delta h p z}{V^2/g}$ by multiplying by $\frac{\gamma}{\gamma}$. if the pressure loss is assumed to take place between two points at the same level. Equation at (32) can be rearranged as-

$$\frac{\Delta h p z}{V^2/g} = f_3\left(C_c, Ap, \frac{L}{D}, \frac{Z}{D}, \frac{V D \rho}{\mu}\right) - (33)$$

3.11. Since the effects of the viscosity are of secondary importance and the drag inside the well screen is almost entirely the influence of the jets issuing from the screen openings, therefore, the Reynold's number and the roughness parameter can be neglected from the consideration and the equation (33) reduces to-

$$\frac{\Delta h p z}{V^2/g} = f_4\left(C_c\ Ap \frac{L}{D}\right) \text{ - - - - - - - (34)}$$

3.12. Assuming that:

1). there is no acceleration normal to the direction of flow.

2). there is no variation in the velocity across the sections considered and

3). there is no resistance to flow and thus

We can utilize the usual relationship by applying the principles of continuity, energy and momentum.

3.13. Thus we have-

$$Q = V_1A_1 = V_2A_2 \quad \text{------} \quad (35a)$$

$$V_1^2/2g + P_1/\gamma + Z_1 = V_2^2/2g + P_2/\gamma + Z_2 \quad \text{----} \quad (35b)$$

$$\text{and } F_y = \rho(Q_1V_1 - Q_2V_2) \quad \text{-----} \quad (36b)$$

where subscript 1 and 2 correspond to the section shown in the figure (3.8).

3.14. The increament of discharge dQ, through an incmment of length dL, can be shown by the energy and continuity equation to be

$$dQ = Cc\, \Delta p\, \pi\, D\sqrt{2g\Delta h_{pz}}\, dL \quad \text{---} \quad (36)$$

Integrating equation (36) , the total discharge into the screen is

$$Q = Cc\, Ap\, \pi\, D\sqrt{2g}\int\sqrt{\Delta h_{pz}}\, dL \quad \text{--} \quad (37)$$

Now considering section 1 and 2 and applying momentum equation to the flow within the pipe we get equation:

$$A\gamma(h_{pz_1} - h_{pz_2}) = -\rho(Q_1V_1 - Q_2V_2) \quad \text{----} \quad (38a)$$

The differential form of which is

$$-A^2 g\, dh_{pz} = d(Q^2) \quad \text{-----} \quad (38b)$$

If the piezometric head h_{pz} on the entire outside surface is constant, then

$$\Delta h_{pz} = a\ \text{Const.} - h_{pz} \quad \text{----} \quad (39b)$$

Therefore equation (38b) can be written as

$$d(Q^2) = A^2 g\, d(\Delta h_{pz}) \quad \text{----} \quad (40a)$$

Integrating this equation we get:

$$Q^2 = A^2 g\, \Delta h_{pz} + C_1 \quad \text{----} \quad (40b)$$

Since

$$\Delta h_{pz} = \Delta h'_{pz} \quad \text{When } Q = 0$$

$$\therefore C_1 = -A^2 g\, \Delta h'_{pz} \quad \text{-----} \quad (41)$$

Where $\Delta h'_{pz}$ is the difference in piezometric head between the inside and outside of the screen at the point when L = 0. Rearranging, equation (40b) we get:

$$Q^2 = A^2 g\,(\Delta h_{pz} - \Delta h'_{pz}) \quad \text{----} \quad (42)$$

Differentiating equation (42) with respect to L we get

$$\frac{dQ}{dL} = \frac{A^2 g}{2Q} \frac{d(\Delta hpz)}{dL} \quad - - - - \quad (43)$$

When equations 36, 42 and 43 are combined into the diamensionless relationship we have

$$\frac{2 C_c \cdot A_p \pi D \sqrt{2g}\ dL}{\sqrt{g A^2}} = \frac{d(\Delta hpz)}{\sqrt{\{(\Delta hpz)^2 - (\Delta hpz\ \Delta h'pz)\}}} \quad - - (44a)$$

or

$$\frac{C}{D} dL = \frac{d(\Delta hpz)}{\sqrt{\{(\Delta hpz)^2 - (\Delta hpz \cdot \Delta h'pz)\}}} \quad - - (44b)$$

Integrating equation (44b) we get

$$C \frac{L}{D} = \cosh^{-1}\left(\frac{2\Delta hpz - \Delta h'pz}{\Delta h'pz}\right) + C_2 \quad (44c)$$

in which C = 11.31 Cc.Ap. -------- (44d)

Applying the conditions when L = 0 we have $\Delta h'pz = \Delta hpz$, therefore the value of $C_2 = 0$.

Substentuting the value of $\Delta hpz'$ from equation 42, the relation at 44C can be written as

$$\frac{\Delta hpz}{Q^2/A^2 g} = \frac{\cosh \frac{CL}{D} + 1}{\cosh \frac{CL}{D} - 1} \quad - - - - \quad (45)$$

or in terms of velocity

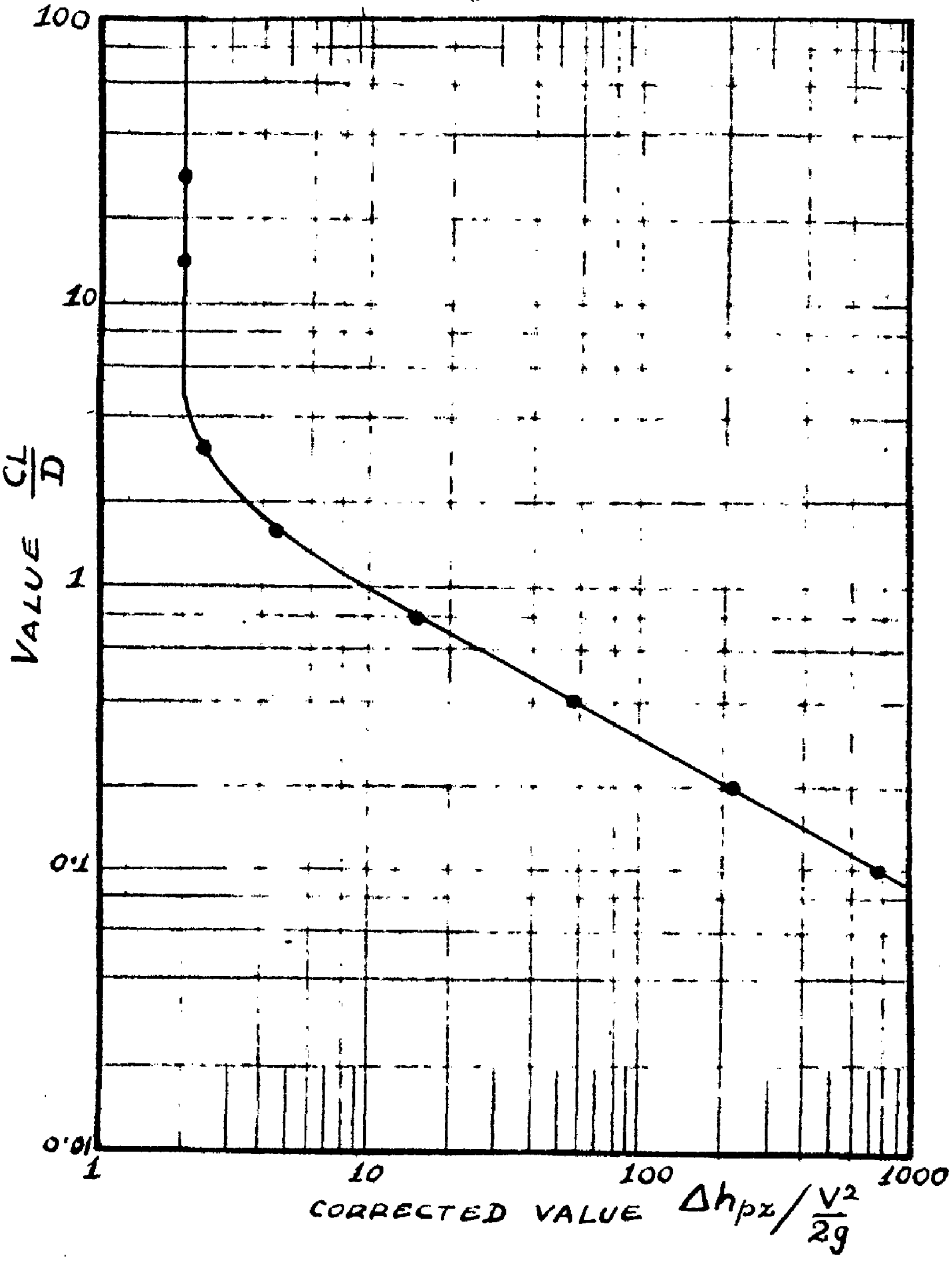
$$\frac{\Delta hpz}{V^2/2g} = 2\ \frac{\cosh \frac{CL}{D} + 1}{\cosh \frac{CL}{D} - 1} \quad - - - - \quad (46)$$

3.15. Thus we find that equation (45) is a specific relationship that combinds the dimensionless parameters Cc, Ap and $\frac{L}{D}$ into a single variable.

3.16. If we plot the two dimensionless parameters $\left(\frac{\Delta hpz}{Q^2/A^2 g}\right)$ and $\frac{CL}{D}$ in the equation (45), we see that loss coefficient factor $\left(\frac{\Delta hpz}{Q^2/A^2 g}\right)$ becomes nearly constant for large values of cosh $\frac{CL}{D}$ and therefore plus or minus one in the equation becomes insignificant.

3.17. S.Peterson and others (1) after taking into account

FIG. 3·17



LOSS CO-EFFICIENT VS. $\frac{CL}{D}$

3.18. A larger value of $\frac{CL}{D}$ than the critical value of six can be obtained by-

(a) increasing the percentage of open area Ap

(b) manuplating the opening in such a way as to increase the co-efficient of contraction Co.

(c) increasing the effective length of the screen,and

(d) decreasing D.

Hence we find that for head loss to be minimum, the percentage of open area of the screen will depend upon L and D But decreasing D also reduces A and consequently increases Δh_{pz}

3.19. The above discussion and experiental verification was related to screens placed in the liquid only (Para 3.9).When the screen is surrounded by gravel or sand the problem becomes more complicated due to several additional factors creeping into the the problem. Some of the important factors creeping into the problem are:

(a) Size of the screen opening in relation to the size of the sand grain or gravel pack.

(b) Size of the gravel relative to the diameter of the screen, and the

the effect of viscosity and boundry zone conditions for flow in the pipe have obtained the graph (fig. 3.17) which closely follows the theoretical graph obtained from equation (45). From the graph it is observed, that the curve becomes asymptotic to a loss co-efficient equal to two. Therefore for practical purposes, the loss coefficient is constant and is equal to a value two for all values of $\frac{CL}{D}$ greater than six. Since the loss co-efficient is a measure of loss, the loss is a minimum when the parameter$\left(\frac{\Delta h_{pz}}{Q^2/A^2 g}\right)$ is minimum i.e., loss co-efficient is minimum.

3.18. A larger value of $\frac{CL}{D}$ than the critical value of six can be obtained by-

(a) increasing the percentage of open area Ap

(b) manuplating the opening in such a way as to increase the co-efficient of contraction Cc.

(c) increasing the effective length of the screen, and

(d) decreasing D.

Hence we find that for head loss to be minimum, the percentage of open area of the screen will depend upon L and D But decreasing D also reduces A and consequently increases Δh_{pz}

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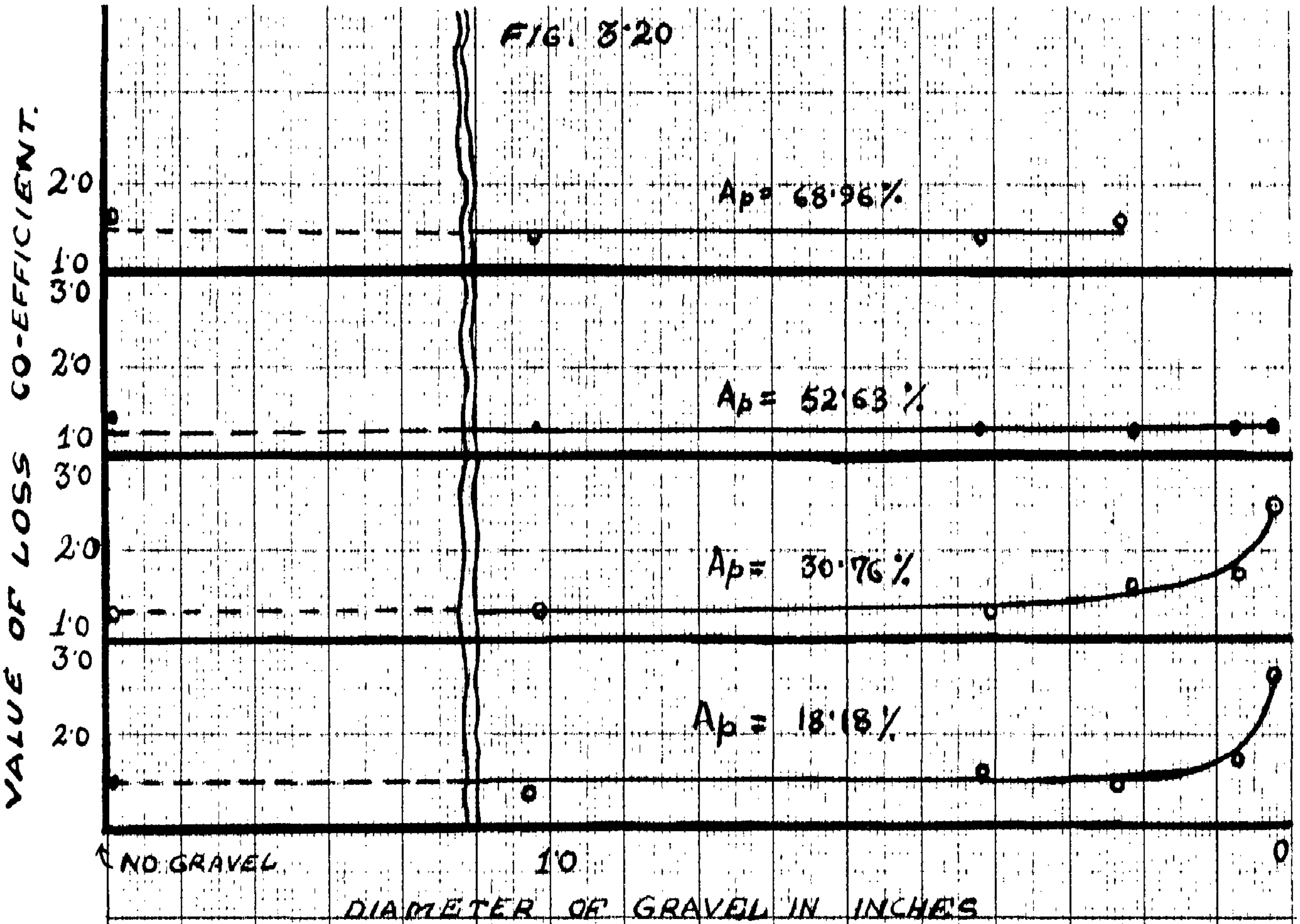


LOSS CO-EFFICIENT VS. GRAVEL SIZE FOR COMMECIAL SCREENS

(c) Standard deviation of the gravel.

3.20. Due to gravel pack, the open area of the screen is partially blocked and to take into account the above factor Peterson etc. (1) have suggested a new screen co-efficient Cs which is expressed as:

$$Cs = \frac{Cc \ Aa}{Ap}$$

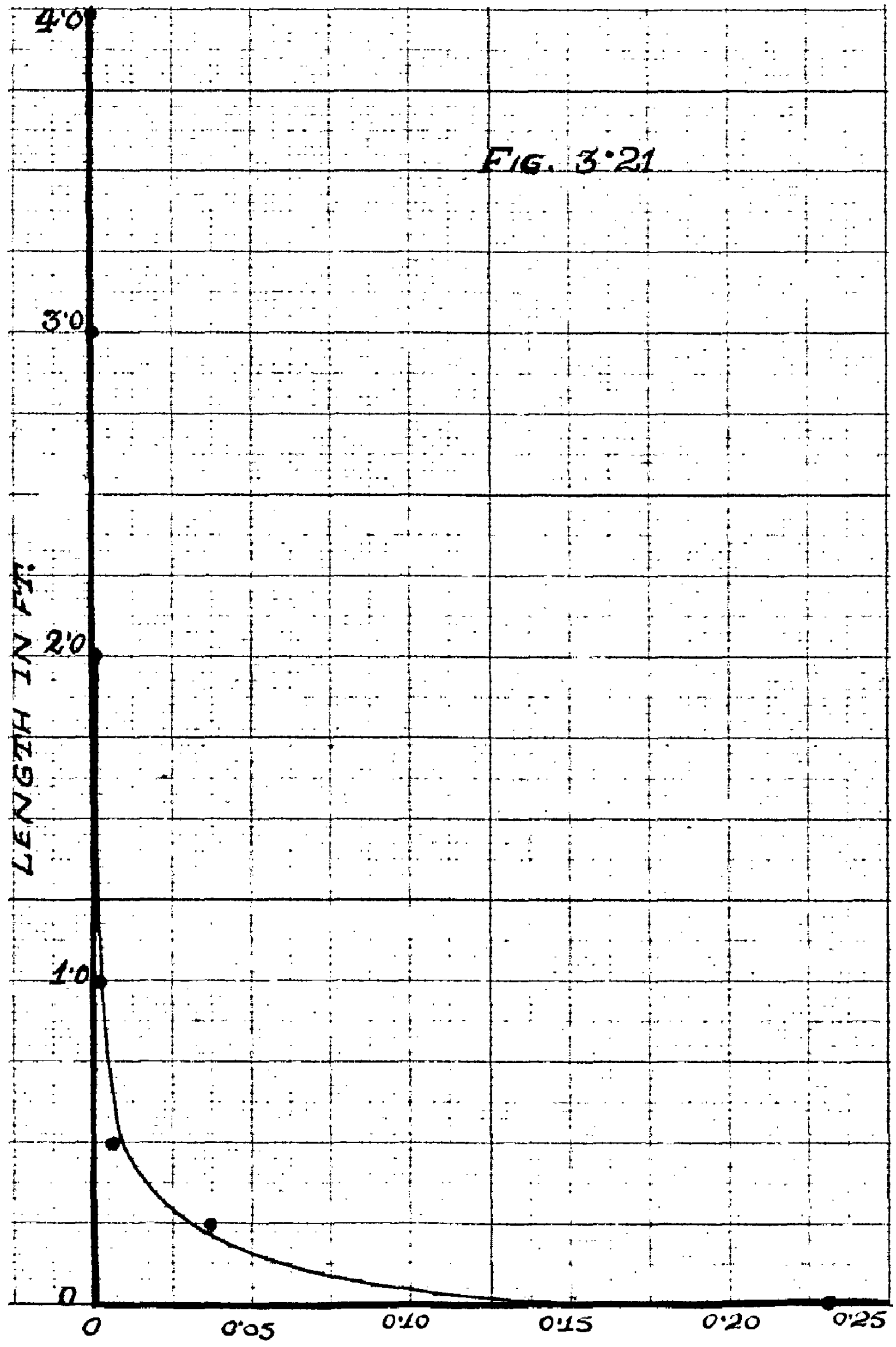
where Aa = percentage of open area when gravel surrounds the Casing The equation (44d) is rearranged as:

$$C = 11.31 \ Ap \ Cs. \quad - - - - \quad (47)$$

in which Cs replaces Cc and includes the reduction factor for Ap. For screen placed in liquids only Cs = Cc. Therefore equation (47) is valid whether the screen is gravel packed or not. Peterson etc. have shown by experiments that loss through the screen is independent of the gravel envelope (fig. 3.20) except when the percentage of open area in the screen is inadequate and the size of the gravel is small.

3.21. Equation (46) above provides a method for checking the head loss incurred by flow through the screen and in the well. Since the head is not constant over the entire length of the screen, the differential head will also vary from point to point over the length of the screen. From graph (fig. 3.21), it will be seen that value of Δh_{pz} is greatest at the discharging end of the screen and decreases with an increase in distance from this end.

3.22. Lab. experiments indicate that practically all the flow into the well takes place only through the length of screen, from the discharging end, necessary to obtain a value of 6 for $\frac{CL}{D}$, therefore better screens must be used at the discharging end of the well.



DIFF IN PIEZOMETRIC HEAD BETWEEN INSIDE AND OUTSIDE OF A SCREEN OF 4 FT. LENGTH

3.23. Since the maximum defference in head occurs at the suction-pipe intake (refer para 3.21), the velocity through the screen in this region will be the greatest, and, consequently excessive sand movement is likely to occur. This fact must be realised while choosing the screen.

3.24. Another theoretical computation has been established by Arnand (2) and has been experimentally verified for a screen surrounded by gravel which shows that the screen length for which loss co-efficient becomes constant h depends upon permeability, K, of the formation and the thickness of the surrounding material.

DESIGN CRITERIA

3.25. Design criteria resulting from equation (45) can be summarised as follows:-

1). To have minimum screen loss, the value of $\frac{CL}{D}$ must be greater than 6.

2). For $\frac{CL}{D} > 6$, the gravel size can be chosen for best sand flow control.

3). The actual head loss for a given discharge for values $\frac{CL}{D} > 6$ depend only on the diameter of the screen. Therefore minimum value of loss can be obtained by manuplating L.

4). The greater part of the flow into a well takes place over the length of screen (measured from the discharging end) required to obtain a value of 6 for $\frac{CL}{D}$. The quality of this section of screen is, therefore, of greater importance than that of the remainder of the screen.

3.26. Gilbert Lee Gorey (3), worked out the relation in screen co-efficient and loss of head and has concluded that when the screen co-efficient is about 15% or greater, it has little or no effect on the loss of head through the screen. But as the co-efficient decreases, the loss in head is very large. Hence for screen co-efficient more than 15% the loss of head will be independent of the shape of the opening (fig. 3.24).

3.27. When the value of screen co-efficient becomes less that 15% the velocity of the jet is increased due to reduced area, Momentum of the jet is increased and a greater amount of energy is dissipated in deflecting the jets through 90°, leading to a greater head loss inside the screen.

3.28. In the province, at present no such design criteria for minimum head loss is being followed. From the survey conducted, it was seen that almost all the wells, whether they were of straight screen type or slotted type, had diameter of 6" and the screen length 100'. It was due to the fact that no such criterias (refer para 3.25) were available in those times. It will, however, be interesting to note that a head loss saving of as low as 1.0 ft.for a discharge of 33500 g.p.sh.(1.5 cusec) from a screen of 100' length, the saving in operational cost will be Rs. 54/- per year approximately as shown below:

$$\text{Saving in H.P.} = \frac{1.5 \times 1.0 \times 62.4}{550} \times \frac{100}{65}$$

$$= 0.262$$

when the pumping efficiency is assumed to be 65%. Assuming average running hours per year to be 5000 hrs.,the cost of units consumed at 5.5 nP. per nit will be-

$$\text{Cost of electricity} = \frac{0.261 \times 746 \times 5000 \times 5.5}{1000 \times 100}$$

$$= 53.54$$

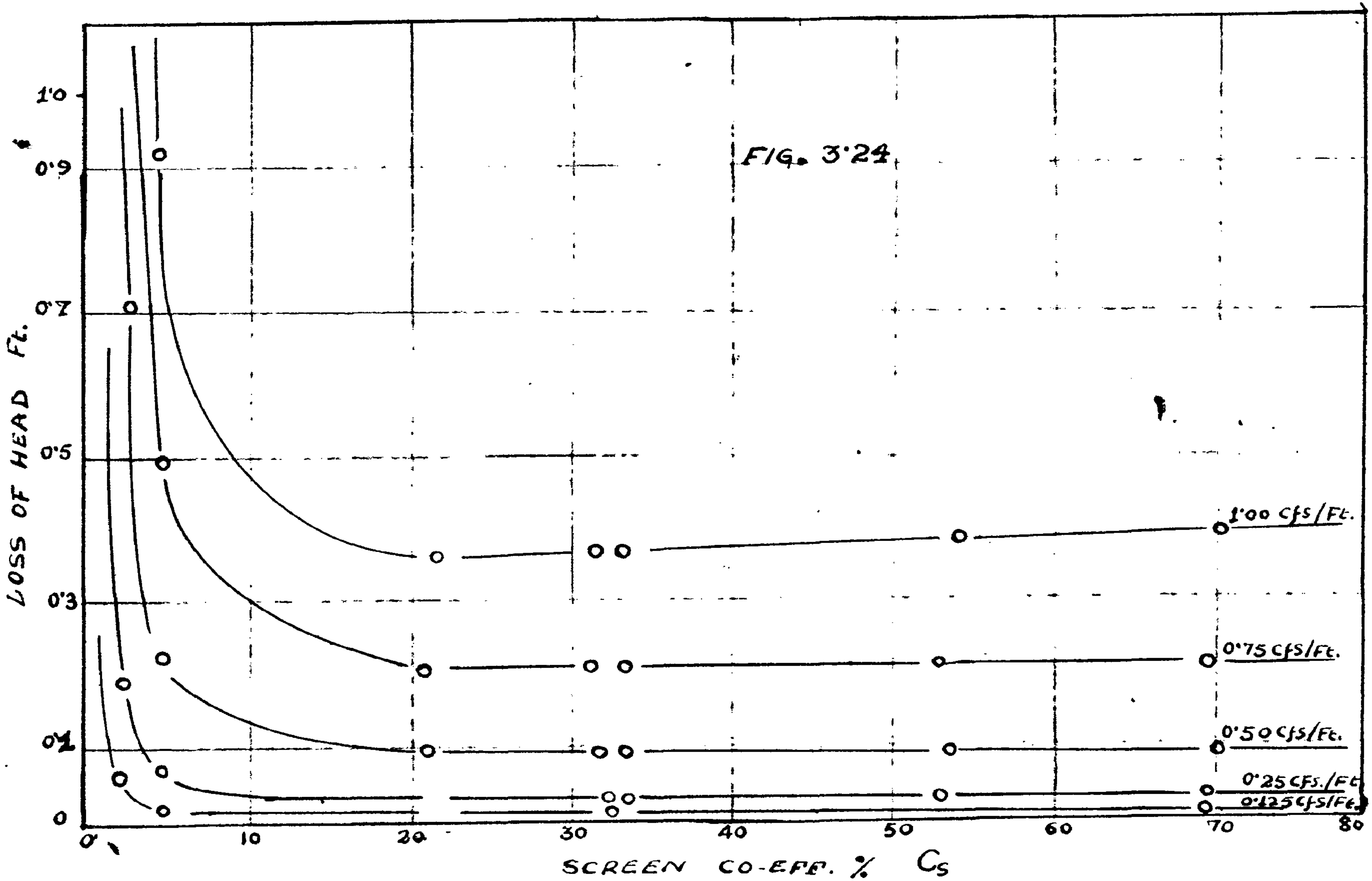

LOSS OF HEAD Ft.
1'0
0'9
0'7
0'5
0'3
0'1
0
0
10
20
30
40
50
60
70
80
1'00 cfs/Ft.
0'75 cfs/Ft.
0'50 cfs/Ft.
0'25 cfs./Ft.
0'125 cfs/Ft.
SCREEN CO-EFF. % C_S

FIG. 3'24

It will be seen that saving in H.P. per well is 0.26 H.P. and for hundred such wells it will be 26 H.P. which can be utilised in some other works.

3.29. In order that the screen for minimum head loss be designed quickly by the working engineers in the field after ascertaining the following factors:-

I. depth of water bearing formation.

II. the size of openings.

III. the size of the gravel or sand in the surrounding aquifer.

IV. size and type of pump and its location.

V. Proposed maximum draw down in the well.

It is necessary that screen co-efficients for various types of screen and gravel size combination be readily available to them. At present no such published data exists in our country. It is felt that the work in this direction for finding screen co-efficients for a wide variety of screens will be of greatest practical value to the Tube-well engineers. The influence of the factors enumerated above (para 3.29) on the performance of a well is discussed in the subsequent sections.

In U.S.A., screen co-efficients of large number of commercial screens with various types of aquifer formations are available (1).

C H A P T E R --- III

S E C T I O N - II

SAND MOVEMENT AND ITS PREVENTION.

SAND MOVEMENT AND ITS PREVENTION

3.28. From appendix B, it will be seen that cause of complete failures or partial failures of deep wells in majority of ncases was due to sand discharge which was either in small or large quantity damaging the pumping equipment, clogging the screen and lowering the efficiency of the wells. Sand discharge actually accelerated the failures in many cases.

3.29. CAUSES: The sand movement is caused due to inherent capacity of water current to dislodge materials which are at rest. The transporting power of a water current is reckoned to vary as the sixth power of its velocity. According to the laws governing the transporting power of a fluid, the diameter of the material, which is carried, increases propertionally to the square of the velocity. An idea of the dislodging power of clear water can be had from the table below when compared to dislodging power of fresh air (7):

Material.	Size-Diameter in inches.	Vel. of water f.p.s.	Vel. of water m.p.h.	Vel.of wind f.p.s.	Vel.of wind m.p.h.
Fine sand	0.0?	6 in.-9in.	0.34-0.51	18	12
Gorse sand	0.04	1.0	0.68	36	25
Gravel	1.00	2.5	1.75	-	100 and above.

When the water holds in it mud in suspension then due to increased density, its carrying power is much increased for the same velocities.

3.30. There is certain critical velocity (6) at which sand of any given grain size will be dislodged from its bed and carried into a well under any constant set of conditions. The sand classification according to American Institute of Mining Metallurgy is given hereunder:-

Material	Aperture size in inches.
Fine sand	0.005 - 0.01
Medium sand.	0.01 - 0.025
Coarse sand	0.025 - 0.062
Fine gravel	0.062 - 0.1

3.31 According to Griffith (8),Parkers table gives velocities above and below which the material indicated is carried or settles in water.

Material.	Vel.f.p.s.	Material.	Vel.f.p.s.
Soft earth	0.25	Coarse sand	0.8
Fine clay	0.25	Sand & gravel.	1.0
Soft clay	0.50	Gravel ½"	1.5
Fine sand	0.7	Pebbles 1"	2.0

Another table giving lifting velocities of sand grains for various sizes in millimeters, with a specific gravity of about 2.65 (9) is as follows:-

Diameter of grains.	Vel.f.p.s.
Upto 0.25	0.0 - 1.10
0.25- 0.50	0.12- 0.22
0.50- 1.00	0.25- 0.33
1.00- 2.00	0.37- 0.56
2.00- 4.00	0.60- 2.60

3.32 Babbit, etc.(9) have suggested a velocity of flow upto 0.2 f.p.s.suitable for wells. But, however, the most suitable velocity of flow of water from consideration of sand movement in unconsolidated aquifer and head loss is 0.10 ft. per sec.(1,10,11) and is widely used for designs in calculating the screen dimentions. Velocity of 2 f.p.s.being considered too high for design.

3.33. INFLUENCE OF CLAY: The wells in India are generally in the unconsolidated formation such as clay, sand and gravel. Commonly the layer of fine sand occurs above the layer of coarse sand. Where fine sand beds are not perforated but coarse sand gravels are, the water from the fine sand beds will run down outside of then casing to the beds that are perforated, washing clay from the intervening beds, causing the water to m be turbid and thus more powerful in carrying sand particles with it (refer para 3.29). The draww-down to the pumping level furnishes the differential head for flow outside the pipe between perforated and non-perforated beds (12).

3.34. INFLUENCE OF SAND PUMPING:- Sometimes minor cave-ins cause the water to became turbid. When enough sand is pumped out of a particular stratum, a cavity will be formed in it and the clay bed above it will sag down, causing a run of clay and sand, and in some cases even collapsing the casing a potential danger for well life.

3.35. INFLUENCE OF CLOGGING:- Clogging of screen perforations due to deposit of sand particles on the openings or clogging due to any other cause reduces the area of openings and increases the velocity of flow through the remainder of the openings thereby causing more sand pumping as time rolls on (Refer appendix B).

3.36. INFLUENCE OF IMPROPER CONTROL OF PUMPS. Improper control of pumps often results in large quantities of water flowing back into a well from the discharge tank under a high head, causing upset in chemical, hydro-static and formation set up conditions within the circle of influence, the deposits of the products of

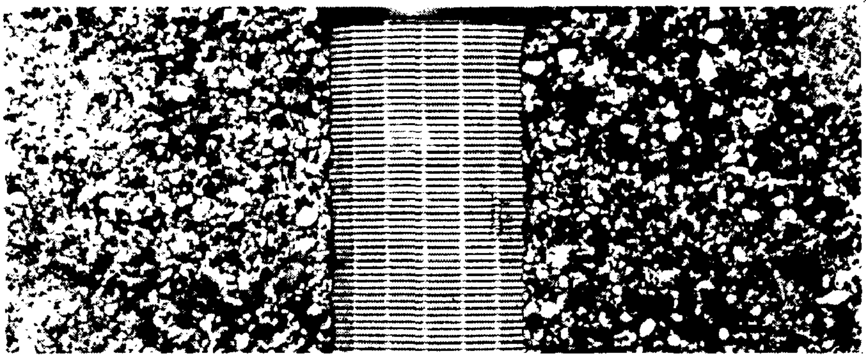


Fig. 3.38. Grain size distribution around the well screen of a properly developed well in an unconsolidated formation (courtesy Edward E. Johnson, Inc.).

corrosion and incrustation on pumps parts and on the interior walls, to say nothing of the continual surging effect to which the well is being subjected. The continual upsetting of the hydro-static conditions in and around a screened well often leads to sand infiltration or sand pumping as well as incrustation (13).

3.37. INFLUENCE OF GRAIN SIZE :- "Sand Gravel" or "alluvial deposits" in which the wells are located vary from the finest particles of sand upto boulders mixed with clay and silt. If the formation is poorly sorted (fig. 1. 22) with small particles occupying the interstices between the larger areas and still smaller particles occupying the space between the small particles and so on, the result is that porosity is greatly reduced. It must be born in mind that it is the percentage of fine, minute particles that determines the yielding ability and not the larger particles. These smaller particles also effect both the performance of a well and its screen and if not controlled and eliminated may cause enough trouble to pumping equipment to cause the well to be rejected as a complete failure.

3.38. INFLUENCE OF DEVELOPMENT :- Previously the main purpose of the screen was thought to prevent sand from entering the well, consequently fine screens were used which would excluded 60% to 80% of the sand. But this concept has changed now altogether. If the screen size is selected properly so as to allow the fine particles of sand surrounding the screen to pass into the well and be removed by pumping etc., then development of an envelope of coarse material around the screen with gradation outward to the original mixture will take place (fig 3.38). In other words, prosperity and size of the particles in the formation surrounding the screen has increased and also the slot opening of the screen. The zone of coarse materials formed will be in somewhat loosen state. The increase in size of particles and slot opening in turn reduces entrance losses at the screen which gives a higher transmitting capacity for the open area of screen of the length used and in this way draw-down is reduced. It also reduces velocity and snad carying capacity of the water, thereby reducing wear on pumping equipment.

3.38. To satisfy all the requirements of para 3.30 to 3.38 above i.e. of (1) Low velocity,(2) Low head,(3) Sand free pumping, (4) non sand clogging and (5) proper development, a careful sand analysis is carried out before the sixe of the opening of the screen slot is decided upon. Analysis of sand and its texture can easily be made by the help of a sieve test which will show the proportions of the sample consisting of specified sizes.

3.39. INTERPRETATION OF SAND ANALYSIS:- Sand analysis graph is first plotted on sand cumulative percent retained basis and the size of grains as ordinate and abscissa respectively. Broad priciples of interpretations from such a graph are:-

(I) Generally, for most sands, screen opening size of which 30 to 40 percent of the sample is coarser is chosen for sand free operation in thelonger run.

II. Sand which is virtually homogeneous with a low uniformity co-efficient, a finer screen is chosen.

III. Sand samples in which smallest size of sand grain is present in the largest proportion, it will be profitable to allow the sand size to pass through the mesh even if it be as much as 70 to 80 percent

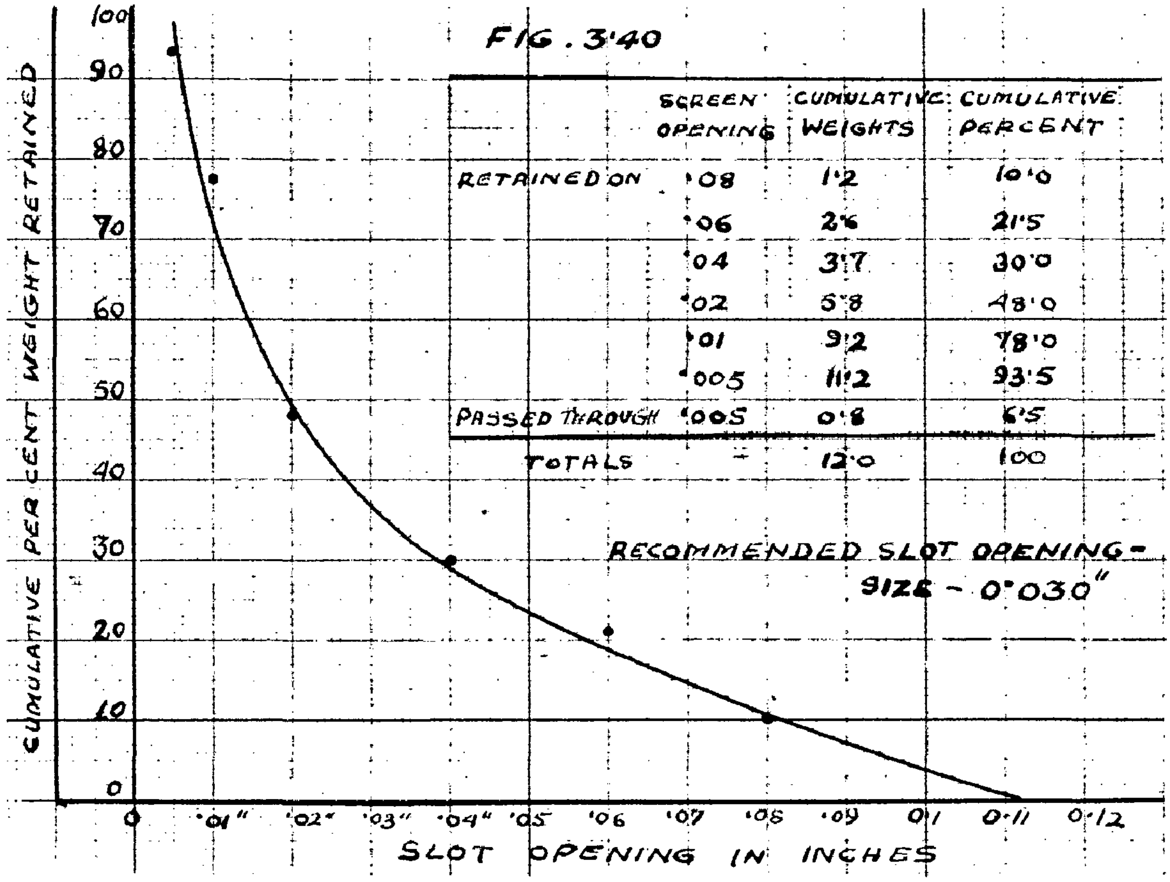


FIG. 3·40

	SCREEN OPENING	CUMULATIVE WEIGHTS	CUMULATIVE PERCENT
RETAINED ON	·08	1·2	10·0
	·06	2·6	21·5
	·04	3·7	30·0
	·02	5·8	48·0
	·01	9·2	78·0
	·005	11·2	93·5
PASSED THROUGH	·005	0·8	6·5
TOTALS	–	12·0	100

3.40 ILLUSTRATION OF SAND ANALYSIS: A typical sand analysis and its graph as outlined in para (3.39) is shown in fig.(3.40). It reveals that the strata sample contains about 30% of fine sand, 25% of medium sand and rest 45% of Coarser material varying in different sizes. The "effective size" is approximately 0.006 in and that the size of which 40% of the sample is coarser is .025 in. approx. The "uniformity" co-efficient is .025/ .006 = 4.2 indicating a medium coarse sand varying considerablp in size of particles. A screen opening of .03" is therefore provided.

3.41. Discussions of para 3.38 and 3.39 show that screen opening size should be chosen such that finer particles of sand in the strata are removed and a large and sand free supply is therefore, ensured with minimum head loss. These finer particles from the strata are removed during the development stage. The development may be carried out either by ordinary pumping or by any other standard methods.

3.42. It is found practically that the texture of sand is not of the same degree every where and even in thesame boring it varies widely in different layers. Discussions of previous paras show that the main object of design of opening is, as far as practicable, to remove the finer particles from the strata around the screen in the maximum quantity. Obviously, therefore, it is of utmost importance that screen openings are provided to match the particular strata. If it is not done then troubles are bound to arise in future.

3.43 OBSERVATIONS ON SURVEY REPORT: On the state wells surveyed by the author (appendix 'B'),this principle of selection of screen was, however, not observed strictly and a common strain-of grain size and degree of assortment of sand. It is apparent that this fact was one of the main cause of wide spread defect of sand discharge and immature failures ofstate wells in U.P.

In appendix ("C"), sieve tests graph of 16 wells (fig. 3.43, A.B.C.) are given where a common screen mesh of specifications given belowwas provided.

SPECIFICATIONS OF STRAINER: Agricultural type, 7" out side dia.Copper woven wire sheet of 8'x22". The 21 S.W.G.ribbon wire should give an aperture of 0.0115" made of 24 S.W.G.Wire to the linear inch in the direction placed together by a series of ribbons alternately 1/16" and 5/16" apart. The Woven Wire 21 S.W.G. and wire by 15x35½ S.W.G.(made from 24 S.W.G.).

However, a study of those graphs indicates that screen specifications for each sample should be differmnt.

3.44 Above discussions show that the proper sieve test of each layer of sand and its correct interpretation is extremely important for high efficiency and longer life of the well and must be done by experienced persons who are well on the job. Sieve tests are nowbeing done at several places for new state wells and mesh is being selected to match the formation, but still at some other places, the sand is being classified by "see and touch" method and meshes of only two or three sizes are being used. This process if continued, will ultimately lead to well disaster in the distant future.

3.45 PREVENTIVE MEASURE FOR DEFECTIVE PUMP CONTROL:- To prevent damage to a well caused by back flow of water under high head (refer para 3.36) an automatic non return valve may be provided somewhere in between the pump discharge end and the delivery. Sometimes a sluice valve is only provided at the delivery side.

But this is not sufficient because the operator sometimes does not close it before cutting the power to the pump and also the power tripping in rural transmission lines is so frequent and sudden that operator can not have any control over it.

C H A P T E R --- III

S E C T I O N - III

S T R E N G T H O F S C R E E N .

STRENGTH OF SCREEN

3.46 A well screen is generally manufactured by cutting, or punching the perforations on a plain pipe and, therefore the pi is considerably weakened. While specifying construction material strength of the finished products must be taken into account. Th screen must be able to withstand lateral earth pressures, pressur due to shifting strata and the gradual weakening effects of corrosion and erosion. It should have sufficient buckling strength to support the weight of casing pipe above. It should not be bent o crushed under these loads. The basic requirements for th proper resistance to stress is the selection of suitable wall thickness and spacing of perforations. The strength of the pipe be forated is decreased considerably if th perforations are in width than the thickness of th metal being perforated

3.47. In addition to above, there are chances of screen being ruptured or twisted from sudden rotory jerks collapse of cavity created in some layer of formation by excessiv sand discharge (refer para 3.34) or faulty construction and location of screen in the well. The selected screen, therefore, must have sufficient strength and ductility to withstand such hazards.

3.48. The copper wire-netting cloth wrapped on perforate pipes as strainers on state wells is very delicate and can be destroyed very easily by small but commonly occuring accidents. The mesh is kept in position on the perforated pipe by soldering it on to the pipe. But th soldering itself is very weak and can b broken by slight heavy jerks. While in transport, a slight dent at any point of the mesh makes the wire flatten which of course is an invitation for rupture by shifting strata. The copper mesh can also be ripped off due to lateral pressure. It is also consi derably subjected to errosion.

3.49. The discussion in para 3.48 shows that the copper mesh used as strainer on state wells is not a suitable article for tube-well construction and in majority of cases will fail comparatively quicker. For economy and longer life, a robust screen is essential for wells. It is believed that a careful selection of screen will contribute more to the life of a well in unconsolidated formation than any thing else. Special attention while selecting the screen must be paid to the portion near the discharging end of the well (refer para 3.22 and 3.23). In this region the velocity and differential pressure will be high and to prevent sand movement more open area must be provided here.

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C H A P T E R - III,

S E C T I O N - IV

CORROSION AND INCRUSTATION OF WELL SCREENS AND CASINGS AND ITS PREVENTION.

CORROSION AND INCRUSTATION OF WELL SCREENS AND CASINGS AND ITS PREVENTION.

CORROSION OF SCREENS AND CASINGS

3.50 GENERAL- The ground water, in general, is corrosive or incrustating. Deterioration due to these factors depends upon the degree of chemical elements present in it. Rate of pumping also excercises a far reaching influence over the life of a well screen. These three phenomenas probably contribute to more screen failures than all other agencies put together (10).

3.51 MECHANISM OF CORROSION:- Iron, and all other metals, when placed in contact with water or a solution, has a definite inherent tendency to go into solution in the form of electrically charged particles (Iron ions), but since the solution must remain electrically neutral, these positive ions can enter the solution only if an equivalent number of positive ions of some other elements are somehow displaced. In case of iron immersed in water, the element immediately removed and plated out on iron is hydrogen which forms a thin invisible film over the iron surface.

The formation of this film obstructs the reaction

(a) by insulating the iron from the solution, and by

(b) increasing tendency of the hydrogen in the film, to re-enter the solution and thus oppose the corrosion. Thus the first stage of the corrosion which was initiated by just immersing iron in water may soon come to a stop and there may not be appreciable damage.

If the hydrogen combins with oxygen present in the solution to form water or it escapes as hydrogen gas bubbles then the original reaction progresses, releasing more iron into the rate determined mainly by the rate at which the hydrogen film is removed and the metal goes on deteriorating. This is the second stage of corrosion and is responsible for the majority of cases. The rate of destruction of hydrogen film depends upo the effective concentratðon of dissolved oxygen in the water, and this in turn depends upon factors such as the degree of aeration of water, whether the water is at rest or in motion, the salts present, the temperature etc.

3.52 The tendency of hydrogen to plate out from a solution increases with the degree of acidity of the solution and, therefore, the reaction in the acid solution is a much more ra and pronounced. This reaction is less rapid in more alkaline solutions. The iron, which enters the solution is soon thrown down as rust and it may further aggrevate the situat permitting formation of additional iron ions from the m

3.53. CHEMICAL REACTIONS OF THE CORROSION PROCES chemical actions can be expressed as follows:-

$$\underset{\text{Metal}}{Fe} + \underset{\text{Ions}}{2H^{+}} = \underset{\text{ions}}{Fe^{++}} + \underset{\text{atoms}}{2H} \quad \text{-----------------} \quad (I)$$

This primary reaction is followed by either (a) the destruction of the hydrogen film or (b) its removal as gas bubbles as shown below:

$$\underset{\text{atoms}}{2H} + \underset{\text{dissolved}}{1/2\ O_2} \longrightarrow \underset{\text{liquid}}{H_2O} \quad \text{---------------------} (IIa)$$

$$\underset{\text{atoms}}{2H} \longrightarrow \underset{\text{gas}}{H_2} \quad \text{------} \quad \text{----------------------} (IIb)$$

The reaction (I) proceeds with the accumulation in the solution of Fe^{++} which is oxidised and precipitated as rust as shown below:-

$$2Fe^{++} + \tfrac{1}{2}\ O_2 + H_2\ O \longrightarrow Fe^{+++} + 2\ OH \longrightarrow \text{insoluble hydroxide (rust)} \quad \text{-----} (III)$$

3.54. ESTABLISHED FACTS REGARDING CORROSION:

(1) In absence of moisture, iron will not corrode appriciably at normal temperature.

(2) Oxygen is usually essential to promote corrosion in any circumstance. Dissolved oxygen alone will greatly accelerate corrosion in acid, neutral, or slightly alkaline water. In ground waters, the rate of corrosion is almost directly proportional to oxygen concentration, other factors remaining the same.

(3) Corrosion is more rapid in acid solutions than in neutral solutions, and the latter is more rapid than in alkaline solutions.

(4) Hydrogen gas is usually evolved from the surface of the metal during corrosion in acid solutions and concentrated alkaline solutions. The evolution of gas is very much less in neutral solutions.

(5) In natural ground waters, the precipitated rust usually carries down some compounds containing lime, magnesia, and silica together with other insoluble materials from water. These substances have considerable influence on the structure and density of the rust coating. A loose, non-adherent coating under ordinary conditions may accelerate corrosion, a uniformly dense and adherent coating may reduce the rate of corrosion very considerably.

(6) Surface films raise the potential of metals and make them more resistant to corrosion.

FIG. 3.56

(7) In most cases the initial rate of corrosion is much greater than the rate after a short period of time.

(8) In natural ground waters, the rate of corrosion generally tends to increase with increase in the velocity of water.

(9) Metals of different composition when come in contact with each other in electrically conducting solution, sets up a difference in potential and thus accelerate corrosion locally.

(10) Corrosion of submerged metals is not uniform over the entire surface and distribution of attach determines the useful life of metal.

(11) Some biological organism,such as anaerobic bacteria, often accelerate the electro chemical process of corrosion.

3.56. LOCALISED CORROSION (PITTING):-There is very serious problem of pitting of blind pipes or screens of wells. Many tubewells had to be abondoned due to defects developed by pitting (refer app.B). Holes as big as about 3" dia have been seen by the author due to pitting in pipes extracted from failed wells in Tubewell Divisions of Muzaffarnagar and Meerut (fig.3.56).

3.57. Pitting is merely a localisation of Corrosion which is taking place. It is caused by concentration of electric currents resulting from potential differences on the metal surface. Factors causing such irregularities are:-

Hetrogeneous structure, metallurgical treatment, surface roughness, scratches, mill scale, openings in applied coatings, differential concentration or composition of corroding solution, stray currents i.e. electrolysis, etc.

3.58 Dissimilar metals when in contact also promote corrosion rapidly. Whitman and Russel found that when copper comes in contact with steel in water, the rate of corrosion is much more than the corrosion of steel only (31). Thus we see that agricultural strainers are naturally more atuned to rapid corrosion.

3.59 Scoffeld and Stenger (32) showed experimentally that metal surface in contact with dissimilar soils when kept moist, activate local corrosion.

INFLUENCE OF COMPOSITION OF SCREEN AND PIPE MATERIALS:

3.60. In commercial iron and steel several elements such as Carbon, Manganese, Phosphorous, Silicon, Copper, etc. are generally found in various degrees of proportions, and some of them have a marked influence on the rate of corrosion in certain media while others have little or no effect.

3.61 CARBON: It has little effect on resistance to corrosion. Chappel (33) from his experiments concluded that corrodibility commercial iron and steel increases slightly with increase in carbon to about 0.89%. With increase in carbon beyond this point, the corrodibility decreases.

Aitchison (34) from his experiments concluded that of the normal constituents of steels, the cementite structure of steel is least attacked.

3.62 MANGANESE:- It does not have an appreciable influence on the corrodibility of commercial steels in which the manganese contents range from about 0.20 to 0.60 per cent (25). When the manganese is associated with unusually high sulphur contents, the rate of corrosion is accelerated and more so in acid media(36).

3.63 PHOSPHOROUS:- Diegel from his experiments reported that high-phosphorous steels are more resistant to corrosion than low-phosphorous steels.

3.64. <u>SULPHUR:</u> In moderate amounts it has very little influence on the corrodibility of steel in neutral water, but the effect becomes more pronounced in acid waters.

3.65. <u>SLICON:</u> Within the range of 1.2 to 2.3 percent, it does not seem to have any influence on the corrodibility of metal either in dilute acid orneutral solution (37).

3.66. <u>COPPER:</u> German State Institute for Testing Materials (38) carried out investigations in various circumstances and concluded that durability of metals exposed to ground water, acidic solutions, etc. was increased by the presence of copper. Steels with higher copper content rusted relatively less.

3.67. <u>NICKEL:</u> Increasing quantities of nickel progressively decreases the rate of corrosion in groundwater, etc. exposure. Howe (39) experimental results on the effect of Nickel on the corrodibility of steel under natural conditions is summarised in table 3.67.

Pilling (40) observed that when copper and Nickel are alloyed together in stebl, the beneficial effects of Nickel are further enhanced. These effects become more impressive as time goes on.

3.68. <u>CHROMIUM:-</u> Tests carried out by Friend, Bentley, and West (41) and Aitchison (42) on specimens of steel containing various amounts of chromium ~~there was practically no loss.~~ Showed progressive decrease in rate of crrosion.

3.69 <u>STAINLESS STEEL:</u> These are highly corrosion resistant steels. Many varieties of stainless steels having different

TABLE - 3.67

TABLE SHOWING EFFECT OF NICKEL ON STEELS

Metal.	Analysis, percent.							Average penetration in per year.		
	Carbon.	Silicon.	Manga-nese.	Phos-phorous.	Sulphar.	Nickel.	Oxides.	Sea-water 2 years.	Fresh water one year.	Air one year.
Wrought Iron.	Trace	0.19	Trace	0.196	0.025	--	1.96	0.00494	0.00338	0.00123
Mild Steel	0.074	0.017	0.31	0.114	0.058	--	0.405	0.00577	0.00329	0.00123
3% Nickel Steel	0.22	0.06	0.90	0.011	0.020	3.18	--	0.00426	0.00281	0.00081
26% Nickel Steel	0.362	0.21	0.68	0.026	0.034	26.44	0.067	0.00132	0.00107	0.00035

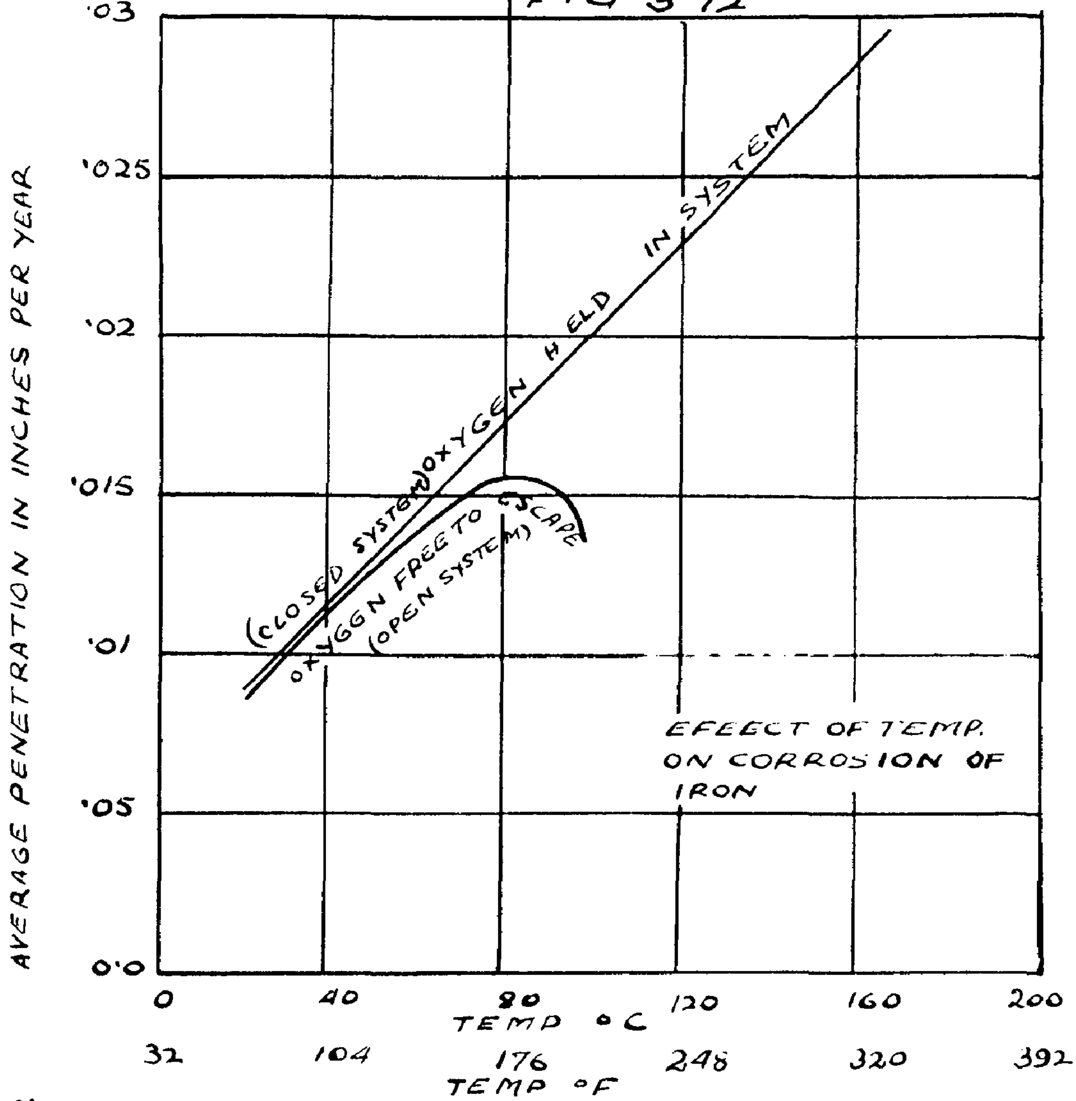
for a variety of applications where high resistance to corrosion is desirable. In fresh water and pure air polished stainless steel is practically noncorrodible. In salt water the rate of corrosion is very much less than the ordinary carbon steel. The rate of corrosion is definitely decreased further by the addition of 2 to 3 percent Molybdenum,. Manufacturing of stainless steel requires very exact controls and is therefore, quite costly.

ARRANGEMENT OF METALS ACCELERATING CORROSION

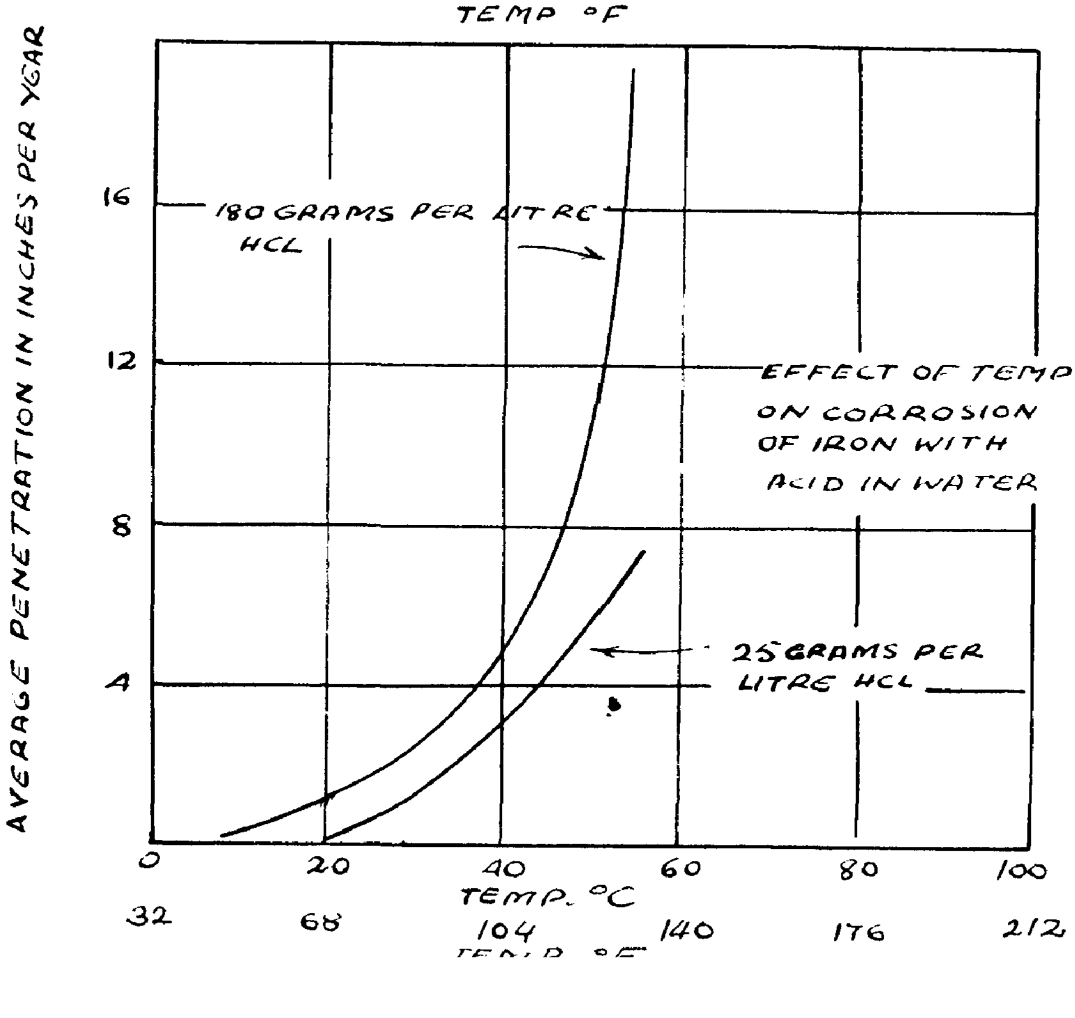
3.70 If metals are arranged in the order of their tendency to corrode galvanically, the following arrangement (43) will result:

1. Magnesium (Corroded End Anodic)
2. Aluminium.
3. Zinc.
4. Cadmium.
5. Iron.
6. Chromium Iron.
7. Chromium Nickel-Iron.
8. Tin.
9. Lead.
10. Nickel.
11. Brassess.
12. Bronzes.
13. Nickel-Copper alloys.
14. Copper.
15. Chromium Nickel-Iron.
16. Silver.
17. Gold.
18. Platium (Protected end □ cathodic).

FIG 3·72



AVERAGE PENETRATION IN INCHES PER YEAR
·03
·025
·02
·015
·01
·05
0·0
(CLOSED SYSTEM) OXYGEN HELD IN SYSTEM
OXYGEN FREE TO ESCAPE (OPEN SYSTEM)
EFFECT OF TEMP. ON CORROSION OF IRON
0
40
80
120
160
200
TEMP °C
32
104
176
248
320
392
TEMP °F



AVERAGE PENETRATION IN INCHES PER YEAR
16
12
8
4
180 GRAMS PER LITRE HCL
EFFECT OF TEMP ON CORROSION OF IRON WITH ACID IN WATER
25 GRAMS PER LITRE HCL
0
20
40
60
80
100
TEMP. °C
32
68
104
140
176
212

The metals grouped together in the above list have small tendency to produce electrolytic corrosion. But when metals separated from each other in the above list, are connected then they tend to corrode the one highest in the list.

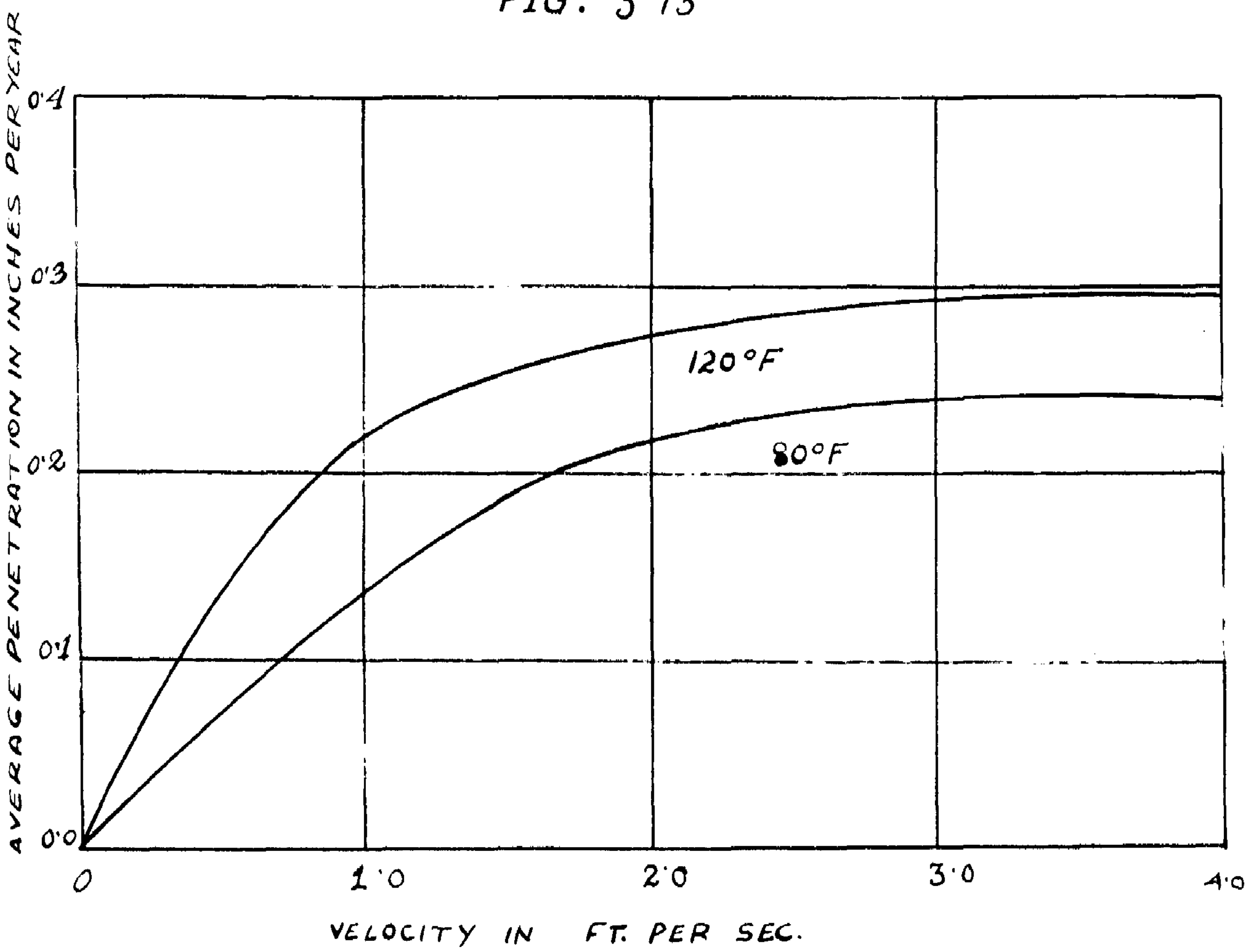
INFLUENCE OF EXTERNAL FACTORS ON SCREEN AND PIPE MATERIALS.

Influence of elements as discussed in the preceeding paragraphs is of relatively minor significance when compared with factors external to the metal itself. The various extemrnal factors and their influence over the corroding action is given in the following paragraphs:

3.71. OXYGEN - Walker (44) and Speller (45) have proved experimentally that corrosion in natural waters is usually proportional to the dissolved oxygen content. Soil waters carry sufficient oxygen to support the corrosion reactions under ground. Corrosion in non-oxidizing acids is also accelerated by the presence of oxygen. Aerated and alkali solutions are generally much more corrosive. The above facts are applicable for both ferrous and non-ferrous metals. In general, the total solubility of gaseous oxygen is greater in a cold than a hot solution. It is greater in pure water than water containing dissolved substancess. At a definit temp it is directly proportional to the pressure. Since the ground water is generally cold and is under pressure, the amount of oxygen dissolved will obviously be more and therefore enhanced rate of corrosion.

3.72. INFLUENCE OF TEMPERATURE: The temperature, on the whole, has a marked effect on the corrosion rate. The accelerating effect of temperature on corrosion in water is shown in fig.(3.72). In acid solutions, temperature also has a marked

FIG. 3'73



EFFECT OF VELOCITY ON CORROSION IN STEEL PIPES
(REF. 52)

accelerating effect. The ground water temperature vary from place to place and therefore the problem of corrosion must be examined by actual site conditions (52).

3.73. INFLUENCE OF VELOCITY: If motion of the corroding solution is increased, the rate of corrosion is also increased because it causes more oxygen to be brought to the surface of the metal. Motion also tends to thin the liquid film on the metal surface and thus reduces the distance through which the dissolved oxygen must diffuse. Effect of velocity on the initial rate of corrosion in a 1/2" steel pipe carrying tap water is shown in fig.(3.73).

3.74. Roetheli and Brown found that at a certain high velocity (not stated) the corrosion rate reaches a maximum and then decreases, because of the formation of a more resistant gelatinous layer of ferric hydroxide. At still higher velocities the rate again increases, apparently because of erosion. Turbulant flow in pipes increases corrosion very much.

3.75. From para 3.73 and 3.74, it is clear that velocity of flow of water into the well should be kept as low as possible to obtain maximum life of the well screens. Also the velocity of axial flow should not be high in the casing.

3.75. INFLUENCE OF INERT GASES: They tend to decrease corrosion as they displace oxygen according to theory of partial pressures.

3.76. CORBON DI-OXIDE: Free carbon di-oxide in the amount usually found in natural water, is not in itself a factor of much importance. Carbon di-oxide acts like an acid and, by increasing the acidity of the solution, accelerates the rate of corrosion. The carbon di-oxide solution easily dissoves the carbonates of calcium and manesium, The amount of carbon di-oxide will determine whether the carbonates which commonly form an important constituent of the protective coatings deposited from water will tend to dissolve or precipitate. In the former case any protective coating which exist may be removed, and in the latter a protective coating may be built up.

3.77 HYDROGEN SULPHIDE:- Hydrogen Sulphide gas when present in ground water makes the water acidic and causes rapid corrosion. It attachs most copper base alloys and produces copper sulphide which is insoluble and may be deposited in the openings of well screens. Thus metal of the screen is eaten away by the corrosive element and the products of corrosion are deposited in the screen openings causing incrustation at the same time.

3.78 DISSOLVED SALTS IN GROUND WATER:- Besides the above gases, many salts and minerals are dissolved in ground water as it trickles down the different stratas of earth. Salts like Potassium Chloride, Potassium Sulphate and Potassium nitrate increase the rate of corrosion. Salts like zinc-sulphate, Sodium-corbonate, Sodium-phosphate, etc. diminishes the rate of corrosion and in some cases may even stop it.

3.79 BIOLOGICAL INDLUENCES:- Certain primitive twing organisms in contact with metals influence the rate of metallic corrosion. Iron bacteria deposite water compounds in the system and thus clog the pipe and increases the friction factor, increasing the pumping cost and loss of head in the screens. Aerobic micro-organism readily developes when the concentration of free or dissolved oxygen is high, whereas the anaerobic bacteria developes when the dissolved oxygen is very less or nil.

3x80 3.80 <u>INFLUENCE OF p^H VALUE:</u> The p^H value is generally controlled by the amount of dissolved carbon-di-oxide and dissolved carbonates and bi-carbonates of the mineral salts. A p^H value of 7 indicates a neutral solution. A p^H value less than 7 indicates an acid condition while value more than 7 indicates an alkaline solution. When p^H is below 4.5 (28), a free mineral acidity is present. In an alkaline solution the corrosion is increased with increase of p^H value. The lowest corrosion rate has been found to occur around p^H = 7.

3.81 <u>SPECIFIC CONDUCTANCE-</u> It is the ability of a substance to conduct an electric current. Waters with relatively high specific conductance can cause corrosion of iron and steel even though other properties may indicate otherwise. Since specific conductance reflects the activity of electrically charged ions in water, it follows that higher the conductivity the greater is the rate of electro-chemical action. The specific conductance of ground waters increases directly with the amount of dissolved minerals in it. The water may be alkaline-characteristic not usually associated with severe corrosion, out, if the conductivity is high, there may appear severe corrosion (46). Estimates of dissolved solids can very conveniently be made by measuring the conductivity.

3.82 <u>CAVITATION EROSION:-</u> It is generally found in the suction side of pump impellers in the tube-wells. It is caused by the formation and sudden collapse of vapour filled cavities by sudden change in pressure. Collapse of a bubble against a solid surface produces pitting which is characterised by having a sharp

Holes in well casings developed due to pitting and corrosion.

granular outline free from corrosion products. The dynamic rapid impact of the fluid makes the metal surface free from natural protective films, causes localised corrosion, fatigue and acceleration of depolarisation (48, 49, 50).

3.83 DEZINIFICATION:- In this type of corrosion, one or more metals of the alloy are changed or removed, leaving it in a solft spongy condition. This type very commonly occurs in well screens manufactured out of brasses with a high zine content and in steels and iron with a high carbon percentage and when these metals are used in conjunction with metals of a higher type. In this process one metal of an alloy is removed due to electro-chemical difference in potential between the metals in the alloy. The failure of the screen is generally sudden.

3.84 DIRECT CORROSION:- In screens of wells results in even uniform destruction or loss of metal over the entire screen surface. The screen openings are enlarged and the metal reduces in thickness. The screens themselves remain intact until they collapse due to loss of strength or enlarged openings leads to excessive sand discharge.

PREVENTION OF CORROSION IN WELL CASINGS

3.85 GENERAL:- As has been pointed out in the preceding discussions, that composition of iron and steel within ordinary range of variation as found in commercial products has little effect upon the rate of corrosion of iron and steel continuously submerged in water. Special alloy steels have been developed which are corrosion resistant. But these are very costly. Out aim must, however, be to have materials which could withstand the ground water corrosion action at least for about 50 years. Certain methods to improve upon the life of materials used on wells are discussed in the following paragraphs.

3.86 In tube-wells, methods of prevention of corrosion hase to be applied both on well screens as well as on casing pipes. The conditions of corrosion in the inside and outside surfaces of pipes and screens are different.

3.87 The inside surface of casing and screen of a well is always immersed in water. Therefore, the oxygen concentration, temperature, velocity of motion of liquid, film formation, dissimilar metals in contact, the hydrogen ion concentration, etc., are more important and usually determine the corrosion rate. The supply of oxygen is limited and therefore the rate of corrosion is slowed down considerably due to this factor alone.

3.90 The corrosion behaviour on outside surface of the pipe is more complex. The outside surface is always in contact with different types of ground stratas and as such both the chemical and physical properties of soil are important. Significant properties of a soil include, its perosity, its power of absorption on metal surface, its conductivity, the contact effect produced by dissimilar solid constituents which it may contain, the dissolved matter and variation in concentration of the substances in solution. The soil stress is also an important factor which can damage the coatings on outside surface.

In general as already said that the corrosion of iron is accelerated locally when in contact with brass, copper, monel metal, or other materials cathodic to iron in a solution of good conductivity. Tong marks on pipes and screens remove mill scale and due to internal strain produced by the cold deformation, these marks corrode more fast and must be carefully avoided during. handling.

PROTECTION OF INSIDE SURFACES

3.91 The inside surface of pipes can be protected by artificial protective coatings. A thoroughly cleaned surface, free from loose scale and foreign matter, is always essential for a satisfactory coating.

3.92 PAINTS:- Paints are not at all satisfactory for underwater treatment. The best non-corrosive paints can protect the surface for few years only, whereas the tube-well requirement is for about 30 to 40 years or more.

3.93 METALLIC COATINGS:- The best known metal coating for iron and steel is Zine applied by hot dip process. Bonilla (51) reported that after 12½ year of exposure in water the galvanised pipe had pitted less than black iron pipe.

3.94 CEMENT LINING OF PIPES: Cement lining of pipes has proved to be one of the best protective coating against corrosion of steel. The pipes so protected have given satisfactory service for 60 years and more (52). Improvements in cements and methods of application has made it possible for its application in more severe corrosive conditions. Uptil now, this process has been used mainly in water supply mains and at few places on wells also with satisfactory results (13). Author believes that this process can equally be well applied for preventing corrosion in tube-well casing pipes and therefore needs further investigations.

3.95 BITUMINOUS COATINGS:- They include refined coal tar pitch, natural asphalts and asphalts manufactured from blown oils. Plasticised coal-tar enamels made under A.W.W.A. specifications 7 - A - 5 and 7-A-6, 1940, when applied not less than 1/16" thick to the interior of pipe while it is revolving provide a in Coolgardie water line showed an average deterioration of 0.01" per year over a period of 12 years (53). These coatings have proved helpful in many cases (22).

PROTECTION OF OUTSIDE SURFACE:

3.96 On the outside surface of the pipe, contact between dissimilar metals, such as copper and iron, should be avoided. This construction often gives rise to accelerated corrosion of the iron at the junction and causes the copper metal to drop out. If it is necessary to have such constructions, then insulating couplings must be adopted (54).

3.97 An extreme variation in the life of pipe exposed to underground soils has been observed. In some cases, there was no effect on pipes even after 40 years of service and in some other cases pipes were eaten away within 3 to 5 years. Considering the variable character of soil corrosion, the engineer should choose the type of prevention which would be more effective and economical.

3.98 BITUMINOUS COATINGS: Generally speaking, in gravel, sand or sandy loam, no protective coating is required or at the most a single reinforced bituminous coating will be satisfactory. But the coating should be at least 1/8" thick and should be covered with a rigid and durable shield of other suitable material to resist distortion. In any case the layer of bitumen next to the metal should be relatively soft to prevent cracks extending to the metal.

3.99 METALLIC COATINGS:- The pipe should be hot galvanized with not less than 2 oz. of Zinc per n square foot of coated surface and be further protected against stratas where the conditions will be severe. Threaded joints of pipes should receive special attention in coating. Metallic coating is useful only when the soil is ux slightly corrosive. Zine coatings corrode rapidly either in alkaline or acid soils.

However, non-metallic coatings have been found to be more durable, 50 to 70 years, and are economical too.

3.100 RE-INFORCED BITUMINOUS COATINGS:- Bituminous materials are widely used for coating metals for under ground use. These coatings include refined coal-tar pitch, natural asphalts, and artificial blown asphalts manufactured from certain kinds of residium oil.

3.102 It is, however, advantageous to reinforce bituminous coatings in such a way as greatly to improve their resistance to abrasion and corrosion for a much longer life. To accomplish this the primed pipe can be coated with hot enamel and spirally wrapped with substantial fabric saturated with a water proofing bituminous mixture. The fabric may consists of saturated felted material. Recently fibre glass fabric has come in the market for re-inforcing pipe coatings.

3.103 In all the wells constructed so far, 6" W.I.Pipe was used as Casing Pipe in the construction of tube-wells and practically no protective coating was provided. Since the wrought iron is very much corrosive in ground water, this type of construction is naturally most unsatisfactory for a long life. The life of a state tube-well has been taken as 50,000 hrs.approx. and the wells run for about 4,500 Hrs. in a year. Thus the life works out roughly to be 11 years. Due to this anticipated short life, no protective measurement, perhaps, are being taken. But if we want to increase the life of a well to 50 years, protective measures have to be provided against corrosion of pipes to keep them serviceable for such a long life.

PREVENTION OF CORROSION IN SCREENS

3.104 The above discussed methods for prevention of corrosion can not be applied to screens due to perforations and, therefore, we have to go for high corrosion resisting alloys which are quite costly. Considerations of heavy costs associated with the failure of the corroded n screens naturally justify the employment of these high priced screens because in the long run they are quite cheap (refer appendix A).

3.105 The most extensively used agricultural strainer for State Wells, which is a tri-metallic construction i.e. of steel pipe, copper mesh sheet and soldering tin is the most unsatisfactory combination from the point of view of corrosion (refer Para 3.90 and 3.96 and fig 3.105). The metal of Tej Strainers and that of W.I.Slotted pipes will also give very poor performance. For best results the well screen as far as possible should be of single material and should have welded joints.

3.106 The metals and alloys which have been developed and

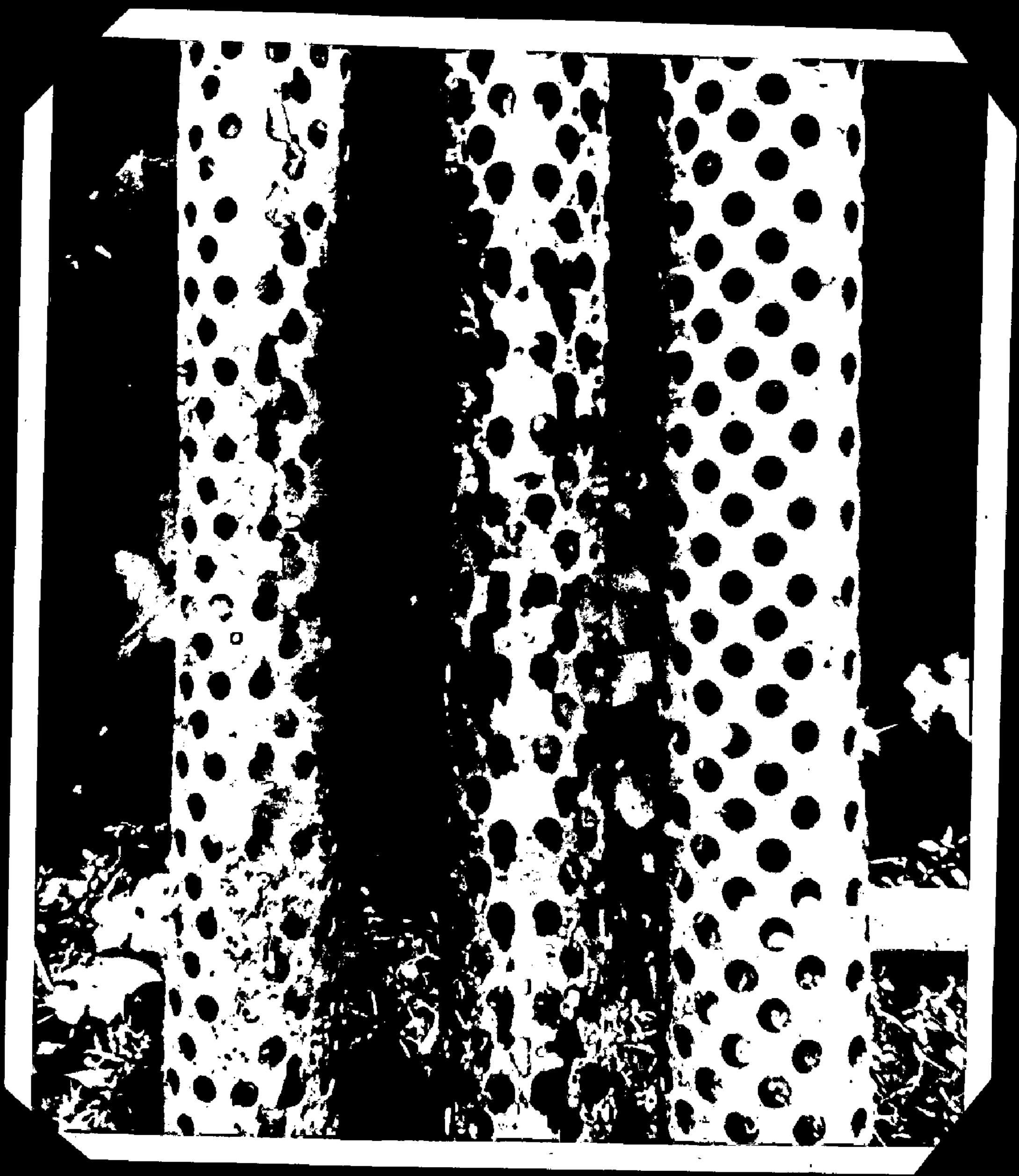


FIG. 3.105 : Corroded perforated tubes of tubewell No.1 South Loi and No. 24A North Loi compared with a new perforated tube.

found to be most affective against corrosion in all kings of soils, ground waters, pressures, etc. are listed below:-

1. Monel Metals (Approx 70% Nickel- 30% Copper)
2. S-uper Nickel(Approx 30% Nickel- 70% Copper)
3. Ever-dur Metal (Copper 96%- Silicon 3%- Manganese 1%)
4. Stainless steel (under passive condition-Low carbon steel 74% -Chromium 18% - Nichel 8%)
5. Silicon Red Brass (Copper 83%- Zinc 16% - Silicon 1%)
6. Anaconda Red Brass (Copper 85% -Zinc 15%)
7. Iron(99.5% and over pure)
8. Stainless steel (under active conditions)
9. Low Carbon steel.
10. Ordinary cast iron.

3.107 STAINLESS STEEL:- Since the stainless steel is non-corrosive as long as it has got a film of oxygen, it is best suited in places where oxygen is present in more than ordinary amount. The stainless steel also have high modulus of elasticity which is a desirable property of slender, cylindrical structure.

3.108 EVERDUR METAL:- It contains no zinc and is, therefore, more anti-corrosive than any other brass-alloy. Due to presence of manganese and silicon, it has more tensile strength and weldable quality.

3.109 POLYTHYLENE STEEL:- The most recent development for anti-corrosive well screen is the introduction of a new high quality plastic material, polythylene, the x properties of which make it a sample ideal protective agent for screen against corrosion. Polythylene is a paraffin of a tough leather likes character and has excellent resistance against chemical influences

The new plastic material has gained outstanding importance and they are now being widely used in Germany (55) on account of their cheapness in comparison to copper, Bronze or Stainless steels. Now a days the Imperial Chemical Industries of India have also introduced what is known as alkathene pipe and they claim it to be a good substitute for pipes and screens. But i-t has not been tried so far on the State Wells.

3.110 CATHODIC PROTECTION:- The cathodic protection counteracts the corroding effects of the current flowing from the metal suface of the local anodes. In this process a galvanic cell is formed by making a good connection in between cast or extruded anodes made of special magnasium alloys and the metallic screen to be protected. The protective current flowing from the anode through the electrolyte to the cathode has a direction reverse to the local corrosion currents emerging from the local anodes to the surface to be protected and thus fully compensate the local currents. This method of protection has become very popular in U.S.A . and Germany during the last 5 or 6 years. (55). But this method is quite delicate and calls for the services of an experienced engineer.

3.111 COUPLINGS:- It will be the ideal thing if the screen and the casing pipe for a well would have been of the same material. But since the cost of the screen material is very high as no protective coating can be provided on it, the pipe and the screen must necessarily be of different materials from the point of economy and waste. This situation results in the accelerated corrosion at joints. Therefore to prevent corrosion special insulated couplings must be employed at joints.

3.112 We thus see that choice of right material for a well screens calls for an exact study about the dissolved subs - tances in the ground water and of (1) pH value(2) Specific conductance (3) dissolved oxygen.Material should be selected on the result of such studies.

INCRUSTATION IN WELL SCREENS:-

3.113 Incrustation is defined as clogging or stoppage of a well screen including the water bearing formation surrounding it, which is the result of deposition of materials in,on, and around the openings of the screen and the voids in the water bearing formation in which the screen is placed.

3.114 The causes of screen incrustation in order of their occurence are:-

(i) Due to precipitation of materials carried upto screen in solution by the water being pumped such as the carbonates of calcium and magnesium.

(ii) Incrustation due to deposition of materials carried upto the screen in suspension by the water being pumped such as clays, silts, mica,alluvium, etc.

(iii) Stoppage due to Iron bacteria.

The incrustation problem belongs to class I above The Chief incrustating agent is calcium carbonate, though in a small quantity, but it is usually the cementing agent.

3.115 The capacity of water to absorb carbon-di-oxide depends upon its temperature and pressure. The colder the water and greater the pressure, more gas the water will abstract absorb and hold Corobon-di-oxide absorbs a considerable amount of calcium carbonate and other incrustating materials.

3.116 When the pumping is commenced the water level in the well and in the formation drops. This creates the pressure difference. The pressure in the entire area is also reduced as velocity head and friction are set up when the water is set in motion. Due to lowering of pressure carbon di-oxide from the water is released and the salts are also precipitated and are deposited where the reduction in pressure is maximum which is obviously on and around the openings of well screen.

3.117 PREVENTION OF INCRUSTATION IN WELL SCREENS :- From the cause, it is obvious that it can only be minimised by reducing pressure difference on the screen openings. To meet this objective we must (a) select a screen which will permit water to enter into the well with least resistance at screen openings and (b) reduce the pumping rate by increasing the period of pumping. Failure due to incrustation and failure due to corrosion is indicated by a gradual decline of pumping level accompained by a fall in capacity.

3.118 Incrustation is generally of two types. Hard type known as sulphate type requires more strenuous treatment whereas the softer type or carbonate type of incrustation varies from a light fluffy-like deposit to a sticky, pasty sludge and is easily removed.

3.119 There are several methods for reclaiming an incrustated screen such as compressed air, water or gas, and dry ice, but the acid treatment is most popular and effective among all.

3.120 ACID TREATMENT:- The single acid treatment of well is done by hydro-chloric acid. Generally 28% acid is widely used. The acid is poured into the well with the help of a pipe which must extend a feet or two less than the screen depth. The acid is heavier than water but it quickly mixes with it. The acid is allowed to remain in the screen from one to two hours and then stirred with the pipe. Thus outside weaker acid is replaced by strong acid. It is then allowed to stand for at least an hour and then stirred again. This process is repeated for 8 to 12 hrs. The well is then surged with a solid block for a few minutes to break loose any incrustation and force the remaining acid out in the formation. It is then allowed to stand for about 3 to 4 hrs. and again surged heavily for a short time and then cleared out.

3.121 DOUBLE ACID TREATMENT:- It is used in places where the formation is high in organic and clayey materials. The general procedure is the same as that of single acid treatment except that sulphuric acid is used after one application of hydro-chloric acid. Heat of reaction and gases produced break down the organic and clayey materials. After the work is completed, it should be ensured by litmus paper that there are no traces of acid left in the water.

3. 122 DRY ICE TREATMENT:- Dry ice is nothing but carbon di-oxide gas compressed into solid form. The solid gas quickly changes from solid state to gaseous state generating considerable pressure in the well when mixing with water takes place. The rapidly expanding gas forces out from the screen and in this way loosen the clogging material. A-bout 20 to 50 lbs of dry ice

is required to do the job. There must be about 11 lbs. of water for every 1 lb. of dry ice used otherwise the water of the well may freeze. Dry ice works better in deep wells with a considerable depth of water.(10)

3.123 AIR TREATMENT:- Air under pressure is suddenly discharged into the well. Shock and difference in pressure loosens the accumulation on the screen. This method is useful if the clogging material is soft and is not recommanded for hard type of incrustation.

C H A P T E R - III

S E C T I O N - V.

DESIGN CRITERIA FOR OPTIMUM DIMENSION OF SCREEN.

OPTIMUM DIMENSIONS OF SCREEN.

3.124 As stated previously the well screen is the most important component of a well structure and upon it depends the losses, yield, efficiency and ultimately the pumping economy. It is, therefore, very important that its dimensions are designed carefully so as to keep losses low and the efficiency high with minimum cost.

3.125 WELL DIAMETER: From equations (26) it will be seen that discharge-

$$Q \propto K$$

and also

$$Q \propto \frac{1}{\log \; X_o/X_w}$$

3.126 For a particular formation, the value of K can not be altered. Also from table below it will be found that with substantial changes either in X_o or X_w the discharge Q changes very slowly. The values of $\frac{1}{\log(X_o/X_w)}$ are as below which show that its value does not alter much:

X_o in feet.	WELL DIAMETER = X_w 4 in.	8 in.	12 in.	24 in.
500	0.28	0.31	0.33	0.37
1000	0.26	0.28	0.30	0.33
2000	0.24	0.26	0.27	0.30

3.127 A relation obtained by Bennison (10) between diameter of the well and the discharge is shown in fig.(3.127). All conditions being identical, a 6" well yielding 33,000 g.p.h. at 18' depression will yield 41,000 p g.p.h. only i.e. about 23% more only if the diameter is increased to 12". If the diameter is further increased to 48" in.,the increase in yield will be

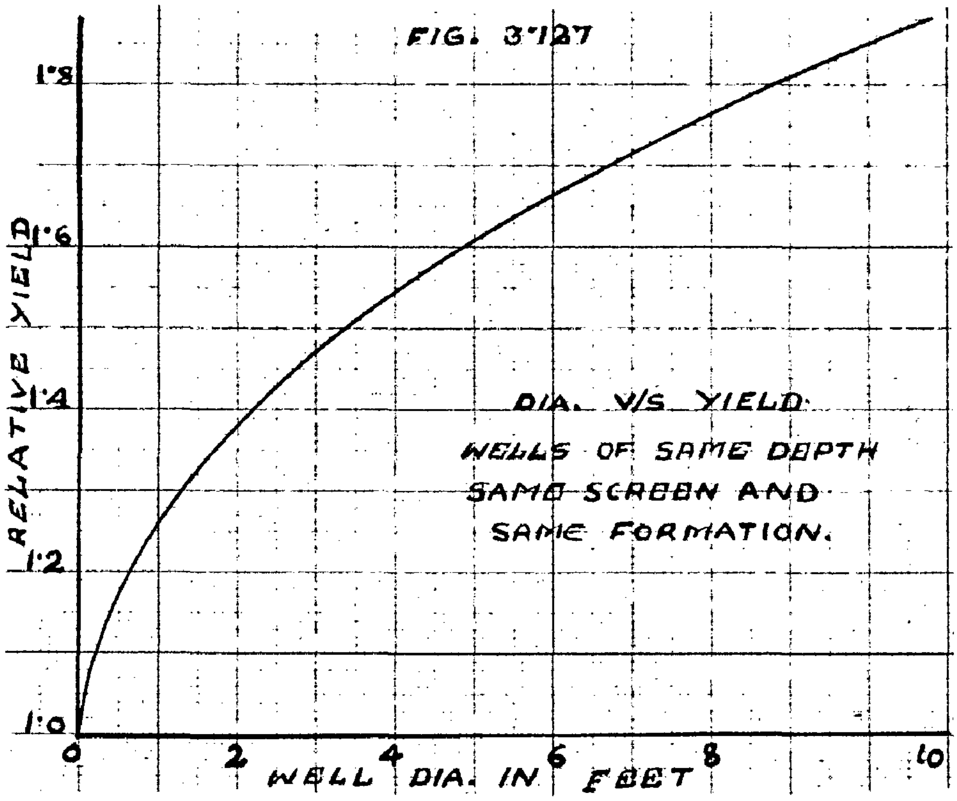


FIG. 3·127
1·8
1·6
1·4
1·2
1·0
RELATIVE YIELD
DIA. V/S YIELD
WELLS OF SAME DEPTH
SAME SCREEN AND
SAME FORMATION.
0
2
4
6
8
10
WELL DIA. IN FEET

about 40% more i.e. 46,000 g.p.h. approx. Therefore the suitable choice of the diameter should be such as it will make the formation yield available.

3.128 DISCHARGE VELOCITY: Before finally selecting the dimention of diameter, considerations of the velocity allowed through the top of the tubo to obtain certain discharge must be taken into account. For pumps, most designers choose a velocity from 5 feet to 15 feet per second. The lower the velocity, the bigger will be the diameter of tubo. The cost of pipe increases very rapidly with the increase of diameter. On the other hand the friction losses increase very much with the increase of velocity if the diameter is reduced (refer to para 2.37) which will increase the operative cost. Therefore, considering all these aspects and the erosion problem, a velocity of 8 to 10 f.p.s.(15, 27) is taken as to be satisfactory in design of well diameters.

3.129 If Q is the discharge in c.f.s. of the well, then cross-sectional area of tube required in sq.ft. is-

$$A = \frac{Q}{V}$$

Where V = velocity in fts per sec.

From these calculations, nearest possible choice of the diameter of a commercial pipe is made. For example for a discharge of 33,000 g.p.h. the area of cross-section of the pipe, taking axial velocity of flow to be 8 f.p.s. will be

$$A = \frac{33000 \times 10\ 144}{60 \times 60.4 \times 8} = 26.4 \text{ sq. in}$$

$$\therefore \quad D = 5.8 \text{ in. (Say 6 inches.)}$$

3.130 Join (27) established an empirical relation for calculating the diameter of the well. His formula was

or it can be said that $Q \propto D^2$
But this is not true (refer para 3.127) and the calculations basod on this formula will lead to wrong results.

3.131 If the axial velocity of flow is kept constant through out the tube, then the diameter of the pipe should go on decreasing from top towards bottom, because the discharge from different stratas of the well goes on adding as the water travels up-wards. It is obvious that stepping down of the radius of well screen and the casing pipe will reduce the cost of the structure. But for each step a reducing socket has to be provided which in turn will increase the cost. One or two steps may be economical and the cost should be worked out from actual price for each case. No such practice however is being followed at present on state wells.

SCREEN LENGTH

3.132 Many relations from theoretical considerations have been formulated to find out the length of the screen but the results sometimes do not tally in actually practice for the reasons that there are several variables in the formula which must be determined very accurately to arrive at correct and definite conclusion.

3.133 The screen length, however, must be chosen correctly. If it is too long, the h cost of the well is increased un-necessarily. In case it extends above the pumping level then besides water it comes in contact with air and thus the rate of corrosion and incrustation is increased which will cause the screen to fail more rapidly. If the length is too short, then the yield from the well may not be satisfactory.

THEORETICAL RELATIONS FOR SCREEN LENGTH

3.134 CALCULATIONS BASED ON PERCOLATION RATE:- Sanghi(15) deduced the following formula for discharge from a well.

$$Q = 2\pi L\, P\, d\, \log x \qquad -(48)$$

where L = length of strainer; d = depression

X = radius of strainer and

P = rate of percolation of water.

Also we have $Q = A \times V$.

$$= \pi \times X^2 \times V \qquad -(49)$$

From equations (48) and (49) we get

$$L = \frac{V}{2\,Pd} \times \frac{X^2}{\log X}$$

If V and d are constants, then the factor $\frac{V}{2Pd}$ will be constant say K^1 since for a particular area the rate of percolation is constant. The strainer length can now be expressed as $L = K^1 \frac{X^2}{\log X}$ ---- ----- ------(50)

If $X \doteq 1$, the value of L will become infinite and negative. Therefore for all real and finite values of L, the value of X must be greater than one. $(X > 1)$.

For finding the minimum screen length, differentiating equation (50) and equating it to zero we get-

$$X = e^{\frac{1}{2}} = 1.646$$

substituting in (50) the minimum length

$$L(min) = K \frac{e}{\log e^{\frac{1}{2}}} = 2\,K^1 e. \quad ---- \quad (51)$$

3.135 To determine the minimum length of the screen, a correct valuation of P is necessary. Nature of sub-soil strata changes from place to place and, therefore, the value of P will also change from place to place. But, if, data is collected on a sufficiently large number of wells, average value of P can be ascertained by standard statistical practices for the area and used for designing a new well.

3.136 CALCULATIONS BASED ON REQUIRED YIELD:- The expression for discharge Q from a unconfined well (refer para 2.34) can be arranged in the following manner (23).

$$Q = K \frac{dh}{dx} \times 2\pi X \times (L + d - h^1) \text{ ----- } (52)$$

where d = depression inside the well and h^1 is the depression at a distance X from the axis of the well and,. Other notations have the usual meaning. Assumptions made are the same as discussed in para 2.32.

Assuming Q to be constant and integrating equation (52) within the limits $X = X_W$ and $X = X_O$, the expression for discharge becomes

$$Q = \frac{2\pi Kd (L + d/2)}{\log (X_O/X_W)}$$

3.137 In the above equation there are two uncertain factors K and Xo which are extremely difficult to be determined correctly. Value of K may vary widely for the surrounding soil and the radious of influence is theoretically infinite. Practically the value of Xo may vary 500 feet to 2000 feet and in some cases even to 3000 feet (10).

3.138 Apart from theoretical considerations there are certain important factors mentioned below which influence the choice of screen length:-

1. Slot open area per foot of screen.
2. Physical and hydraulic characteristics of formation.
3. Cost of screen.
4. Desired yield from the well.

The selection of screen is generally a compromise between cost and hydraulics of screen structure.

3.139 CALCULATIONS BASED ON SCREEN OPEN AREA:- The screen should be such that-

(a) it gives a minimum entrance losses by providing maximum open area,

(b) It must conform to the needs of the formation.

Question naturally arises as to what can be considered sufficient open area in a well screen. The slot opening is fixed by formation and therefore the length must be fixed by the considerations of entrance losses.

3.140 Bennison, etc. (9.10) recommended a velocity of 0.10 to 0.25 f.p.s. for incurring minimum losses. However, a velocity of 0.10 f.p.s.(11) has been found to be a good basis for well design. A factor of safety of about 20 to 25% in excess of the calculated screen length must also be made to allow the adverse effects of gradual reduction of screen opening by mineral deposition over a period of years or clogging by sand.

3.141 For example let a well be required to pump 33000 g.p.h. (1.5 cusecs approx.) of water from a well. Taking design velocity for flow of water into the screen to be 0.1 f.p.s., a screen having 1.5/0.1 = 15 sq.ft.of open area will be required. Allowing 20% excess for incrustation etc., the screen open area should be 18 sft. or 2592 sq.in. Suppose that formation permits slot opening of 0.02 in. only. Selecting 6 in. diameter (refer para 3.129) continuous-slot well screen for the desired opening which has 39 sq.in. of open area per foot of length, the screen length will be 2592/39 = 66 ft. Allowing for clogging, the screen length will be 80'. If a screen of different design is chosen which has got lesser open area per foot of length, then in order to keep the velocity down to the value 0.1 f.p.s., the length of the screen will have to be increased accordingly to obtain the same discharge.

3.142 While calculating the screen length in the above para, only the hydraulic chargacteristics of the well screen were considered and the characteristics of the formations were ignored except that the slot opening to fit the sand grading. It was also assumed that water bearing sand formation will yield the assumed quantity of water. The influence of other characteristics of formation are discussed in para 3.147.

3.143 INFLUENCE OF DRAW-DOWN ON SCREEN LENGTH:

Equation (27) can be written as

$$Q = \pi K \frac{(ho-hw)(ho + hw)}{\log (X_o/X_w)}$$

If the depression ho - hw is very small then the above equation can be arranged as:

$$Q = \pi K \frac{2\, ho(ho-hw)}{\log (X_o/X_w)} \quad --- \quad (53)$$

which shows that

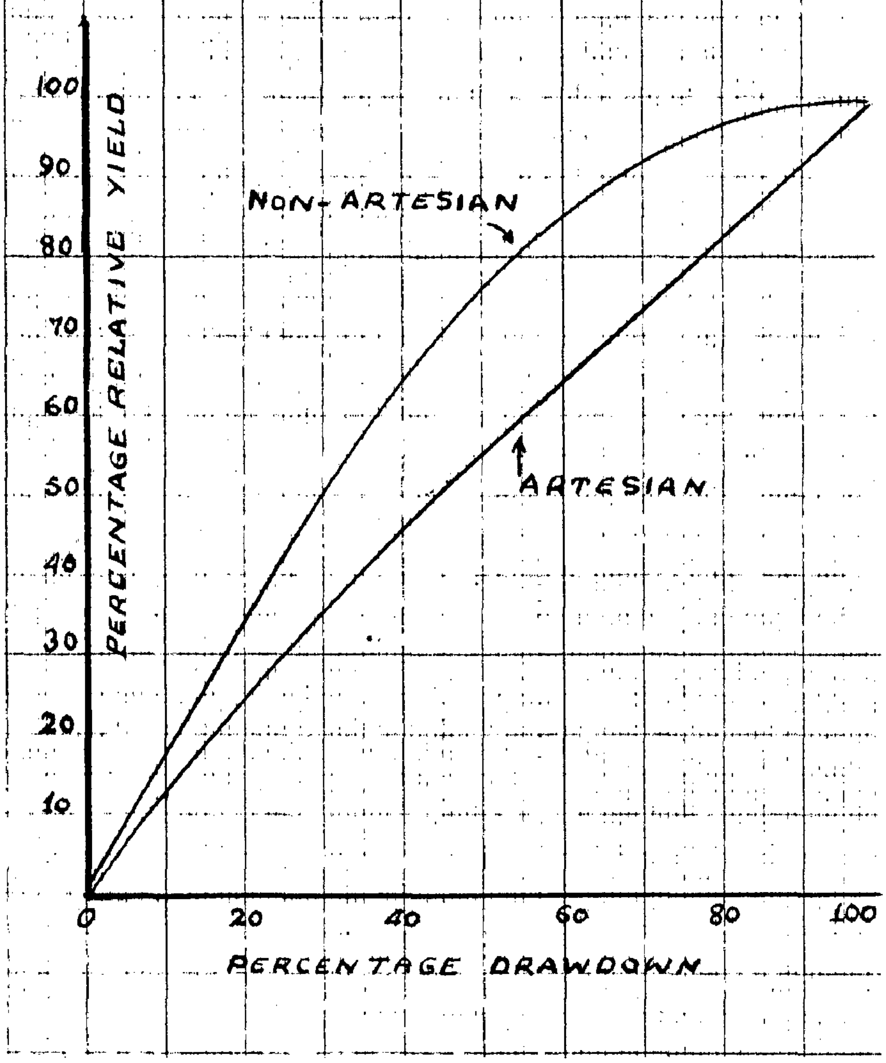
$$Q \propto ho$$

$$\propto ho-hw$$

$$\propto 1/\log \frac{Xo}{Xw}$$

3.144 But as a matter of fact Q is not directly proportional to draw-down i.e.(ho - hw). For small values of draw-down the direct proportionality exists. When (ho-hw) becomes a considerable proportion of ho then the proportionality no longer exists and follows a curve. A curve (10) showing the relation of per cent relative yield to per cent draw-down for confined and unconfined

FIG. 3·144


PERCENTAGE RELATIVE YIELD
100
90
80
70
60
50
40
30
20
10
NON-ARTESIAN
ARTESIAN
0
20
40
60
80
100
PERCENTAGE DRAWDOWN

that for unconfined aquifer, the departure from proportionality starts at about 30% draw-down. Similar results (fig. 2.38) were obtained by Rora bough (66). For artesian aquifer, the relation follows an almost straight line.

3.145 While choosing the screen length, the conditions for available draw down are that -

(a) Screen must not be exposed to air

(b) Maximum specific capacity is obtained from the well.

3.146 From experience it has been found that 50% draw down is quite satisfactory. From the graph (3.144) it can be inter-prested that in a well of 100 ft. of static water depth, a 50% draw-down will extract nearly 76% of the maximum yield of the well while still 50% of the water depth is left for installing the screen and only 24% is left in quantity of water if 100% draw-down was created. If the formation is such that sufficient area could be provided in a still smaller length to keep the velocity at 0.1 f.p.s. through the screen, more draw-down with more yield can be achieved, but it will increase the cost of pumping more with less advantage of yield. Thus for best design of screen length, the product of draw-down and the specific capacity should be maximum.

3.147 <u>INFLUENCE OF CHARACTERISTICS OF FORMATION</u>:- Some times the calculations based on open area for screen becomes in-sufficient when the formation's physical characteristics i.e. static water depth, thickness of aquifer, arrangement of fine and coarse layers of sand are taken into account. Also the choice of best screen length differs for confined and unconfined aquifer conditions.

3.148 CHOICE IN CONFINED AND UNCONFINED AQUIFERS: In an unconfined aquifer from considerations as discussed in para 3.146 and because the draw-down caused by pumping unwaters the upper part of the unconfined water bearing formation in the vicinity of well, the screen length seldom exceeds 50% of the saturated depth. But for a confined aquifer where the sand is more or less of the same grading from top to bottom, screen length as to take about 70 to 80 per cent of the thickness of formation can be provided (11).

3.149 INFLUENCE OF GRADING OF FORMATION:- When the formation is not of the same grading throughout the depth then a careful judgement is required for choosing the right screen length. As a rule (1) the screen must be long enough to take in the major portion of the most permeable strata penetrated by the well and (2) each section of the screen must have the right size of the slot opening to permit proper development of each level. Some useful practical propositions for determining the correct length of a screen in different types of formations are given below:-

I. When the coarser part of the formation is of considerable thickness, finer stratum above need not be screened.

II. When coarser part of the formation is thin, then its entire thickness must be tapped and the screen must extend well up into the finer material above.

III. When coarser material is above fine sand, both stratas must be screened to get maximum yield.

IV. Alternate layers of coarse and fine sand require screen long enough to pick up flow from best strata.

3.150 EMPIRICAL RELATIONS:- Jain (27) suggested the following empirical relation to determine approximately the strainer length for a well-

$$L = \frac{Q}{18\ K\ \pi\ D}$$

where L = length of strainer in feet.

Q = Discharge in gallons per hour at approx. 18 ft. depression.

K = Characteristic discharge per sq.ft. per ft. of depression.

D = diameter of tube-well pipe.

The value of K in this formula has to be determined for different places by actual observations. For the Western region of U.P. the value of K ranges from 8 to 12.

For example, in order to get a discharge of 33,000 g.p.h. from a well having 7 in. overall dia well screen, the strainer length L will be-

$$L = \frac{33000}{18 \times 10 \times \frac{22}{7} \times \frac{7}{12}} = 100 \text{ ft.}$$

3.151 From discussions of paras 3.124 to 3.149, it will be seen that the design of dimensions of a screen are influenced by (1) the hydraulic characteristic of screen structure to give minimum loss and (2) the characteristics of formation to give the required yield. The choice of dimensions should, therefore, be made on the following lines:-

I. The diameter of the screen should be selected from the consideration of permissible velocity of discharge of water from the well (refer para 3.125 to 3.130).

II. To keep the screen losses at minimum, velocity of flow into the screen should not be more than 0.1 ft./sec. (refer para 3.140).

III. The length of the screen should be calculated on the basis of open area per square foot available in a particular screen, (para 3.140 and 3.141). Formation characteristics should also be taken into account (refer para 3.149) while selecting the length. If the formation is such that it does not permit a desired length of screen then either a smaller discharge or an increased cost due to increase in dia has to be accepted.

IV. If the co-efficient of screen C (refer para 3.142) be known then in order to have minimum screen loss a compromise has to be made in between L and D to keep the factor $\frac{CL}{D}$ 6.

<u>COMMENTS ON SURVEY</u>: On State wells as revealed by survey report (appendix B) a screen length of about 100 ft. and diameter of 6 in. was used almost in all cases. As the required yield was 1.5 cusecs, the 6 in. diameter was provided to keep the discharge velocity within permissible limits (refer para 3.129). The open area per foot length of a screen having 0.115 in. opening (this opening was used on state wells, refer para 3.43) is 0.315 sq.ft.(27). To get a discharge of 1.5 cusecs, the length of screen required will be $\frac{1.5}{0.315} = 48'$ approx.

Allowing 20% for clogging etc., the desired practicable length for a yield of 1.5 cusecs = $\frac{48 \times 120}{100}$ = 58 ft. Say 60 ft.

The calculations above show that the 100' length of the strainer used on wells was quite excessive in length and it should be chosen as detailed in para 3.152.

TYPE AND SHAPE OF OPENINGS IN A SCREEN

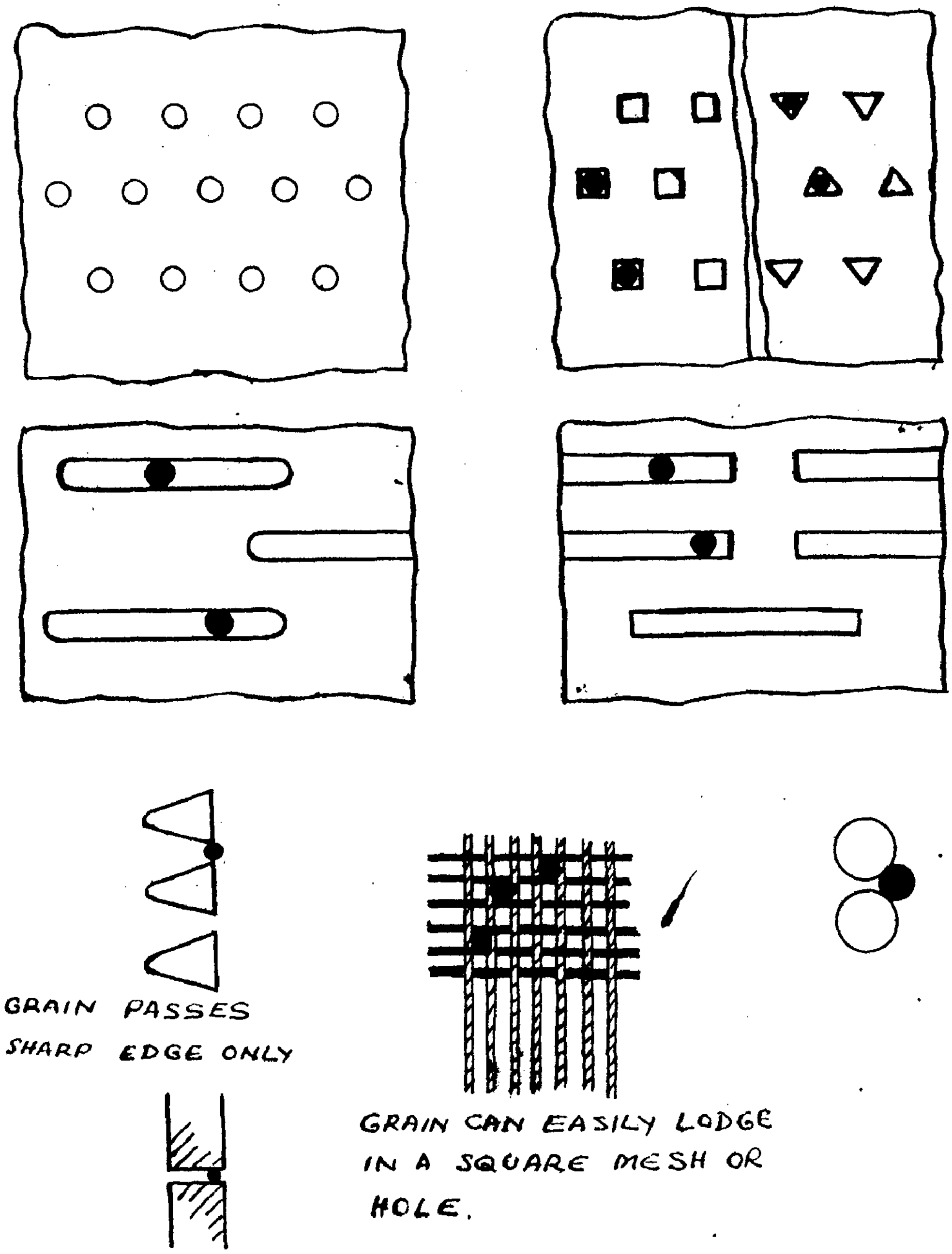
3.152 The type and shape of screen slots influences the transmitting capacity, life, performance and operation of wells in any unconsolidated formation. They play a very important part in development work as some formations can not be developed at all without jamming the screen openings with sand or else allowing too much sand to pass into the well. It is, therefore, essential that a well screen has openings which will allow development of the formation under any circumstances without interruptions.

3.153 SHAPE OF OPENING:- Shape of screen opening should be such that it produces a stream line flow, offers least resistance to flow and should be able to free itself quickly from the sand particles sucked in with water. When a screen is placed against a formation, the sand particles settle in and around it and partially close the openings. Such blocking may be 100% in case of square or circular openings to about 50% in the case of V shaped openings (fig. 3.154 A).

3.154 In square or circular openings, the sand grain has to travel the entire thickness of the tube metal. The duration of entanglement is more and there are great chances of clogging the openings (fig. 3.154F). Openings also, should be rectangular because the grain can not close a slot completely as it makes contact at two points only of the slot (fig.3.154B).

3.155 Further, it is desirable that a slots should be of V shape having the narrow part of the slot next to formation and the V broadening gradually inside. In this case sand grain has to cross only the sharp outer edge of V opening and will be pumped out quickly with water. The chances of clogging are thus

Fig. 3·154


GRAIN PASSES
SHARP EDGE ONLY
GRAIN CAN EASILY LODGE
IN A SQUARE MESH OR
HOLE.

Slot number.	Gaugo Number.	Slot number.	Gauze number.
6	90	25	30
8	70	35	20
10	60	50	12
12	50	100	1/10 in.
18	40	125	1/8 in.

For example slot No.12 indicates an opening of 12/1000 in.=0.012 in. Those screens at prosent are not oasily available in Indian markot but thoy are being used extensively in foroigh countries (10, 11, 21).

3.159 Continuous slot screens have their area more evenly dividod over the surface of the screen and responds to development work magnificiently thon any other type of screen because the sand and gravel particles mostly "bridge" over the screen openings and not the surface between the openings.

3.160 <u>BRIDGE SLOTTED SCREENS:</u> In this design, the material of the pipe is only pressed to protrude to a certain extent, thereby forming small bridges with lateral longitudinal slots. Space between the underside of the protruded material and the outer surface forms the slot opening which can be made of any sizo to meet the requirements of the formation. This type of screen has become very popular and dominates now the field of well screens (55).

3.161 The bridge slotted type of screen has got many advantages over the sumple perforated screens:-

1. The slots of any size can be producod than is possible with the simple slot perforations. The width of

the slots of the latter is always dependent on the thickness of the wall.

II. The screen is more rigid since the bridges are placed on the outer surface of the tubes.

III. The bridges offer greater resistance to compressive, tensile and buckling stresses.

IV. The slots formed by the bridge can not become x clogged and therefore offers low resistance to fluid flow.

3.162 It is, therefore, recommanded that such type of screens i.e. continuous slot or bridge type may immediately be introduced on state wells. Though their initial cost is about 3-4 times higher than the cost of agricultural strainers, but their long life, efficient behaviour, response to development work and low maintenance cost definitely balances the initial high expenditure in the long run (appendix A) and ultimately they become economical and give far better carefree service.

3.163 STRAINERS:- The idea of strainer originated from the needs of preventing sand infiltration into the well. Ordinarily a strainer consists of a wire netted cloth wrapped round a perforated or slotted pipe. About 1/4 in. x 1/2 in. thick 4 to 6 numbers of steel flat bars are welded over the pipe longitudinally so that the mesh does not come in direct contact with the pipe and the mesh. The wire-mesh cloth is available in different sizes of openings e.g. .01 in., .008 in., etc. and can be selected to match with the particular formation.

3.164 Since the strainer cloth is made of round wires, the slot formed by the wires of the strainer cloth resembles a V shape opening with broader side of V resting directly against the formation which gradually decreases towards the centre of the thickness of wire (fig.3.154}D). Mechanically this type of opening is a sand catcher and clogging is therefore bound to occur. Also the very construction of strainer does not give straight and stream lined passage for flow of water and eddy currents are formed in the annular space between the wire net and the perforated pipe. It causes considerable friction and consequent loss of head at the strainer entrance.

3.165 <u>TYPES OF STRAINERS:</u> Out of many kinds of strainers, Ashford, Brownlie, Esbes, Tej and agricultural types are in common use in India.

3.166 <u>OBSERVATIONS OF SURVEY:</u> Study of State wells spread over a wide area revealed that almost on all wells agriculturmdal type of strainer was used and most of the well troubles arose from the faulty behaviour of this strainer (appendix B). This type of strainer was introduced some 30 years back when the science of Tubewells was not much developed. It has, however, been found that despite large scale troubles and failures, no redical modification has been made uptilm now in the use of strainers and they are still being used extensively on new wells as such.

3.167 As discussed in paras 3.90, 3.168, 3.163 and 3.164, the agricultural strainer is much more attuned to (1) corrosion (2) sand clogging and (3) give more head loss producing larger depression and higher operational cost. As a matter of fact it is out of date and is not at all satisfactory.

Therefore immediate introduction of some efficient and durable screen on lines as suggested in para 3.162 is necessary for better economy and longer life of State wells.

greatly reducod (fig. 3.154 C) in this type.

3.156 TYPE OF OPENINGS:- Many types of screen openings are being used such as squares, circles, ellipses, crosses plain a straight sided, rectangular shutters, etc.,and the percentage opening area vary with each type, Maximum opening is obtained in a continuous slot screen.

Perforations of screen, it is apparent, weaken the pipe considerably, especially, if the metal being perforated. Also field results have shown that vertical perforations if properly spaced, have better performance (10). A better screen therefore should have vertical type openings with V shape as shown in Fig.(3.150 C) and should be of considerable strength to withstand the lateral pressure of formation and the weight of the casing above (refer section III of chapter III).

3.157 SOME MODERN EFFICIENT DESIGNS OF SCREENS/~~CONTINUOUS~~ CONTINUOUS SLOT SCREEN:

In this type of screen a narrow metallic ribbon is wound spirally round a skeleton structure of longitudinal roads. It has got all welded construction and non-clogging continuous slots. It provides the maximum inlet capacity for water than any other type of screen i.e. it has got the maximum open area than any other screen. A good continuous slot screen has sufficient strength and ductility to withstand sudden twists (10).

3.158 These screens are available in U.S.A. and continent in a wide variety of slot sizes which are designated in thousands of an inch and are equivalent to standard gauze numbers as shown below:-

3.168 <u>CHOICE AND SELECTION OF WELL SCREENS:</u>- From the discussions of section I to V of chapter III, it will be seen that selection of proper screen for a well is a tricky problem as it incorporates many variables which are to be carefully dealt with. Broadly speaking a good well screen must satisfy the following requirements:-

I. It should provide the maximum amount of open area consistent with its strength, loss, and grading and thickness of the formation (refer para 3.32, 3.39, 3.40 3.47, 3.48 and 3.149). The draw down factor (refer para 3.145) must also be taken into account.

II. For minimum head loss (1) a compromise should be made in L and D so that the factor $\frac{CL}{D} > 6$ (refer para 3.25) and (2) the velocity of flow into the screen should not be more than 0.1 ft./sec.

III. Openings should be of such design, shape and type that it would lend itself to the surging and development work (refer para 3.41, 3.153, 3.154) to bring the screen to its maximum transmitting capacity and at the same time be free from clogging and sand discharge. V type openings are most suited for this purpose.

IV. Metal of which the screen is constructed should be such that it would not deteriorate by chemical action of ground water and also by any of the acids used in acid treating of screens at later stages. (refer para 3.106, 3.120 to 3.122) It should be able to give a satisfactory service life of 40-50 years.

V. It should be strong enough to withstand the least possiblo vibratory explosive force to redevelope the well (dotail discussion in chapter V).

Requirements of items I,II and IV are mostly satisfied by a stainless steel continuous slot or bridge type of screen having V shaped openings. It can also be made sufficiently strong as to satisfy the requirements of item V above.

3.169 If we want a life of a well to be 50 years then naturally we have to incorporate all these improvements and fineness in design of screens. To have a longer life, all the materials used in well should be of superior quality and well screen should be the best. For it is the screen which largely determines the sucess or failure of a well. Most efficient well screens as recommanded in para 3.162 which are available in foreign markets are very costly. Their cost is about 3-4 times more than the ordinary strainer screen used hither to. As stated in beginning the unpopularity of tube-well scheme lies in its high cost of production. It has been argued in the past that employment of costlier screens in well construction will increase the cost of production further. But the survey and the cost analysis based on it reveals a totally different picture and provides a definite powerful argument for swinging the opinion in favour of use of costly screens.

3.170 The cost analysis (appendix A) reveals that an efficient screen of superior quality, on the basis of 35 years of average life gives:

1) A 9.6% less running cost than an ordinary strainer screen.

2) A rate of return 2.06 in excess to that of an ordinary screen on capital investment.

3) The capitalised value of excess profit earned by

a good and well designed screen in 35 years is Rs. 48,200.00 per well, which is more than the cost of two new high priced wells.

3.171 From the cost analysis we see that screen of very high quality and good design be chosen. High quality means longer operating life, less maintenance and smoother operation. Quality of screen is not just a luxury but they make real economy in the long run.

3.172 It is further suggested that the extra profit earned by the wells using quality screens must be reaped back with further research programmes on tube-wells.

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C H A P T E R - IV

GRAVEL PACK WELLS.

SYMBOLS USED IN CHAPTER-IV

a = Cross-Sectional area.

d = dia of pipe or stream tube.

d_s = dia of sphere or sand grain.

f = co-efficient.

h = head loss in ft. of fluid flowing.

l = length of soil column.

lp = length of stream path.

P = Percent of sand by weight having a given dia.

S = Shape factor.

V = apparent mean velocity = Q/a.

Vp = true mean pore velocity.

μ = absolute viscosity.

γ = kinematic viscosity.

ρ = density.

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CHAPTER IV

D E F I N I T I O N S.

1. EFFECTIVE GRAIN SIZE: It is the size of the sand particle of which 90 percent of the strata sample (by weight) is coarser Larger the effective grain size, the coarser will be the formation, It is denoted as D_{10} size.

2. MEDIAN SIZE: This size is such that half of the material in the sample (by weight) is smaller in dia-meter and half is larger in diameter. It is denoted as D_{50} size.

3. D_{60}SIZE: It is the size of the particle such that 60 porcent of the sample is smaller in diameter than this and 40 porcemt is coarser (by weight).

4. UNIFORMITY CO-EFFICIENT: It is defined as the ratio of the diameter of grain that has 40% of the sample (by weight) coarser than itself to the effective diameter of the formation sample. It is indicated as D_{60}/D_{10}. The unformity co-efficient indicates texture, degree of uniformity and porosity of the formation. Higher the Co-efficient, the lower is the porosity. The value of uniformity co-efficient below 2 indicates 45% voids, between 2 and 3, about 40% voids and between 6 to 8, about 30% voids.

5. P-A RATIO: It is the ratio of D_{50} size of gravel pack to D_{50} size of aquifer.

6. UNIFORM FORMATION: Materials with uniformity co-efficients (D60/D10) ranging from 1.3 to 2 are called the uniform materials.

7. NON-UNIFORM FORMATION: Formation having ratio(D_{60}/D_{10}) 2

CHAPTER - IV.

GRAVEL TREATED WELLS.

4.1 INTRODUCTION: Apart from straight screen wells, the other type of wells commonly constructed are the gravel pack wells. This type was adopted only about 15 years back for the State Irrigation wells system in U.P. and since then hundreds of them have been constructed.

The survey of gravel-pack wells (refer append.B) has ~~xxx~~ revealed that none of them completely failed or was abondoned due to large fall in discharge. On most of these wells the following troubles were noticed:-

I. Constant sand discharge.

II. Frequent heavy repairs.

III. Fall in yield of wells as time rolled on.

Troubles as given in II and III above were largely due to sand movement into the well, through the gravel-pack screen.

4.2 OBJECT: In a gravel-pack well, an ~~n~~ annular layer of clean and well rounded gravel of high permeability about 6 in. to one foot thick is artificially created to fill part of the drilled well round the screen. The basic object is:-

(I) To have a smaller diameter screen and, in many instances, a smaller well casing than ~~xx~~ would otherwise be required.

(II) To improve the permeability in the immediate neighbour-hood of the screen.

(III) To increase the effective diameter of the well.

~~XXXX~~

(IV) To prevent sand movement into well.

(XV) To have wider screen openings than would otherwise be possible if the well n was not gravel treated, and thereby obtaining a better specifien yield from the gravel-pack well.

4.3 Before going for a gravel-pack well, hydraulic characteristics of the formation and the structure must be considered first very carefully, because the cost of this type of well is about 30 per cent more than a straight screen well and it also calls for costlier construction equipment and better technique. In case, if, the maximum amount of water can be developed from a formation without gravel treatment by providing a suitable openings and development, then the gravel pack will be simply un-necessary and waste of money and times both.

PRINCIPLES FOR DESIGN OF GRAVEL PACK.

4.4 INFLUENCE OFX GRAIN SIZE: Forces like molecular attraction, surface tension, capillarity, etc. play an important part while the water is moving through formation and determine the quantity of water which the formation will yield and transmit While drilling a well in a sand gravel formation a keen study of the porosity of formation is needed because the above stated forces will vary according to the porosity of the formation Schlicter (1) made the following important observations regarding the porosity:

I. Grain size does not effect the porosity. If any unit volume is packed with spheres of equal diameter the ratio of voids to non voids is independent of the size of spheres so long as all the spheres are exactly of same size. This ratio is maximum for equal size spheres regaidless of their diameter. For example silt and clay are as porous as z sand and gravel.

II. Irregularity of shape of grains produces a larger possible range in porosity.

III. Degree of assortment changes the porosity to a greater extent (refer para 1.22).

4.5 From geometry, we can easily find that surface area of a spherical grain varies as the square of its diameter while its volume increases as the cube of its diameter. That is smaller the grain z size, the bigger will be the surface forming the voids to hold water. For example a cubic foot of sand composed of grain size of No. 40 screen slot opening will have 1000 square feet of surface area whereas a cubic foot of fine clay will have more than 4 acres of surface area. Force of molecular attraction therefore, will be several times more in the latter case. Capillarity action will also bo more in this case.

4.6 Discussions in para 4.4 and 4.5 naturally indicates that a greater force i.e. head or depression will be required to make the same amount of water flow through a finer formation than a coarse one though the porosity in both the cases remains the same (refer para 4.4-I). If an ordinary screen is provided in fine formation openings will have to be made very small which will mean larger head loss and lesser yield. There will also be danger of its quick corrosion and incrustation and, therefore, gravel pack wells which have relatively larger openings are most suitable to such formations.

4.7 <u>FLOW THROUGH GRANNULAR MEDIA:</u> If we consider the flow of fluid through grannular media in a gravel pack well as being analogous to that through pipes (2), then Weisbach's formula can be written as:

$$h = f \left(\frac{lp}{d} \right) \times \left(\frac{Vp^2}{2g} \right) \qquad (53)$$

where $$f = f \; (Re) \qquad f \left(\frac{Vpd}{\nu} \right) \qquad (54)$$

Also for viscous flow Poiseuille's low holds

$$h = 32 \quad lp.v_p / \; g.d^2 \quad \text{-----} \qquad (55)$$

Taking into account the porosity of the material and the shape factor and with the help of equation (53) and (55), Hickox (2) showed that:

$$f = \frac{64}{V_p \; d} = \frac{64}{R_c} \quad \text{-----} \qquad (56)$$

Relation (66) is also the faimliar relation between friction factor and Reynold's number Re for viscous flow in pipes. Equation (56) was developed for grannular materials for uniform size. If the material is not uniform then some single dia. reprosentative of the mixture can be chosen. Fair and Hatbh (3) showed that when the shape factor is the same for all sizes in mixture then ds (effective) = $\frac{EP}{E(P/ds)}$

4.8 This diameter is known as effective diameter and is the diameter of a group of uniform particles having the same surface - area, volume and shape factor as the mixture. Since these are the only properties of material which enter the qn equation, the effective diameter may be used in all cases.

Equation (53) can now be written as:

$$h = \left(\frac{64}{V_p d} \right) \times \left(\frac{L_p}{d} \right) \times \left(\frac{Vp^2}{rg} \right)$$

4.9 The above relation indicates that for a fixed velocity in certain set of canditions, the head required will be less for larger diameters. Givan (4) modified the above relation at (56) and showed that

$$f = \frac{A}{Re} + B.$$

where x A and B are some dimensionless numbers depending up on packing, shape, distribution, size of granules in beds of mixed and size and shpae of the formation.

4.10 The grannuler media of the same grain size with the same porosity may have different resistance to flow because of the different manner in which the void spaces are distributed x through the media (6)

In the natural formation the flow of ground water is unidirectional. The large axes of the grains, therefore, tend to a lign themselves parallel to fliud flow direction and more elongated grains thus become parallel to the direction of fluid flow (5). Also there is less disturbance in a fluid due to flow around a faired shape particle and hence less resistance to flow (7). But these natural conditions are impossible to be attained in an artificial gravel pack. But for minimum head loss in gravel envelope, the gravel used should be round in shape, clean and smooth.

4.11 Since the gravel can not be packed uniformly around the screen of a well nor their orientation can be arranged as to offer less resistance to flow, therefore, for random packing, with random orientation of individual porticls, it may be assumed that voids are evenly distributed and that the resistance to flow is the same in all directions. (6) and flow into the well is uniform from all directions.

412 A dimensionless approach was made by Rose (24) into the laws of flow of fluids through grannular materials. Head of fluid H, necessary to maintane a flow velocity V through grannular media is dependent up-on.

I. Density - ρ

II. Absolute viscosity- μ

III. Depth of bed-h

XXIV. Diameter of the particles of which the bed is formed- d.

V. Diameter ~~afxkhuxp~~ in which the material is packed-D

VI. Voidage or porosity of the bed-f

VII. Gravitational constant-g.

VIII. Height of the surface roughring of the particle -e

IX. Shape of the particle.

X. Size Distribution of the particles.

By suitable choice of a system of definition, the variables IX and X are made dimension less and can be represented by dimension less groups (Z) and (U) respectively. We can arrange the above variables as $-F\left\{ H^{\varepsilon} v^{\alpha} h^{\beta} d^{\gamma} \rho^{\delta} D^{\xi} \mu^{\theta} g^{\phi} e^{\eta} (f)^{\lambda} (Z)^{\sigma} (U)^{\omega} \right\} = 0$

Solving by dimensionless method we get the following dimensionless groups:

$$\left(\frac{H}{d}\right) = F\left\{ \left(\frac{dv\rho}{\mu}\right)^{\theta} \left(\frac{dg}{v^2}\right)^{\phi} \left(\frac{h}{d}\right)^{\beta} \left(\frac{D}{d}\right)^{\xi} \left(\frac{e}{d}\right)^{\eta} (f)^{\lambda} (Z)^{\sigma} (U)^{\omega} \right\}$$

Assuming for simplicity that:

I. the particles are spherical in shape

II. they are closely graded to a mean size

III. they are very smooth

the variation of three independent variable groups $\left(\frac{e}{d}\right)$, $(Z)^{\sigma}$ & $(U)^{\omega}$ is climinated.

Rose experimentally determined the value of the co-efficients and reported that the above relation could be written as:

$$\left(\frac{H}{d}\right) = \psi\left(\frac{dg}{v^2}\right)^{-1.0} \left(\frac{h}{d}\right)^{1.0} F(f)\ F_1\left(\frac{D}{d}\right)$$

Where is a function of Reynold's number, F(f) is a function of voidage and $F_1\left(\frac{D}{d}\right)$ is a fenction of $\left(\frac{D}{d}\right)$ For very slow rates of flow through grannular media having normal density of packing, the reported that

$$\left(\frac{H}{d}\right) = \frac{1,200\, v\nu}{g\rho d^2} \left(\frac{h}{d}\right) \left(\frac{f}{40}\right)^{-4.0} \text{ approx.}$$

4.13 Above relation indicates that for a certain veloci[illegible] of flow, larger the dia meter of grains, the lesser will [illegible] head loss. Therefore lesser will be the depression in [illegible] pack well in which the size of gravel is many times more [illegible] sand formation grain size. The cone of depression will be more flatter.in the pack.

4.14 <u>CONE OF DEPRESSION:</u> From the shape of cone of depression (figs. 2.35 and 2.37), we see that major portion of head loss in the formation occurs in the immediate neighbourhood of well screen. Besides other factors involved in developing the formula for radius of influence and head loss in Chap.II, one of the cause of increased head loss near the entrance of screen is due to the fact that eddies are formed in the stagnation zone, a little up-stream that the junction of screen opening and results in the lowering of local boundary pressure (8), considering the screen openings as a series of orifices through which flow is taking placo (refer para 3.7). The concept of a gravel pack is based on this characteristic of the cone of defression i.e. it is much steeper near the screen or in other words, most of the head loss occur in the immediate vicinity of screen.

4.15 ADVANTAGES OF GRAVEL-PACK: Discussions of paras from 4.7 to 4.14 indicates logically that if a proper size coarse smooth and uniform grannular media could be provided in the immediate neighbourhood of the well, the advantages from such construction will be:-

I. That head loss will be relatively much decreased for causing certain flow into the well then it mm would require if there was no gravel treatment.

II. That the effective diameter of the well will be increasedn due to gravel treatment and the velocity, therefore, will be reduced.

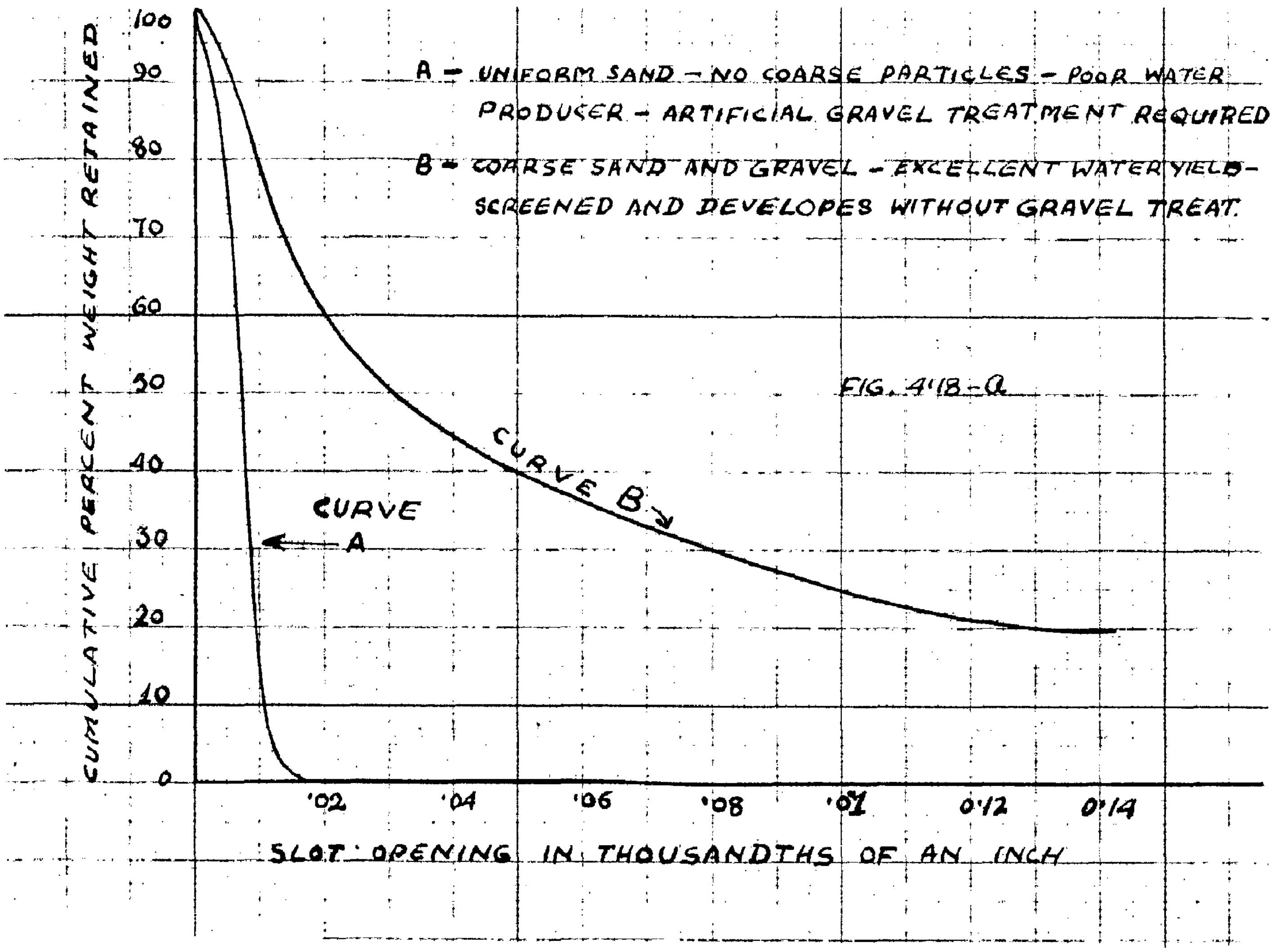
III. That the specific capacity will be increased due to decrease in draw-down for same capacity and reduced entrance friction.

IV. That maximum sand free water can be obtained from the well.

V. Operational cost will be less.

4.16 LIMITATIONS OF GRAVEL SHROUDING: Gravel should not be used indiscriminately in all tube-wells but should be used with a clear understanding and judgement of the formation. Gravel shrouding may not be resorted to in the following cases:

I. If, the quantity of water desired is less than the maximum which the formation can give and which can be obtained by using ordinary straight screen, the gravel treatment in this case will be un-necessary



CUMULATIVE PERCENT WEIGHT RETAINED
100
90
80
70
60
50
40
30
20
10
0
A = UNIFORM SAND - NO COARSE PARTICLES - POOR WATER PRODUCER - ARTIFICIAL GRAVEL TREATMENT REQUIRED
B = COARSE SAND AND GRAVEL - EXCELLENT WATER YIELD - SCREENED AND DEVELOPES WITHOUT GRAVEL TREAT.
FIG. 4·18-a
CURVE B
CURVE A
'02
'04
'06
'08
'01
0·12
0·14
SLOT OPENING IN THOUSANDTHS OF AN INCH

for construction and economic reasons.

II. If the maximum yield can be obtained from a formation with a proper screen, then gravel treatment is un-necessary.

III. According to Bennisom (1), if effective size of the formation is greater than 0.01 inch. and uniformity Co-efficient is more than 2 then the well does not require gravel treatment. If the uniformity Co-efficient is less than 2 then gravel treatment is generally required. No formation, however, whose uniformity Co-efficient is from 5 to 10 need be gravel treated under ordinary circumstances.

4.17 Generally the formations which have comparatively large percentage of coarse particles as revealed by sieve test should not be gravel treated. There is basic difference in between the arrangement of the formation which is naturally developed around a screen well and the granular arrangement in an artificially gravel treated well. In the former case a gradual reduction in the size of the particles away from the screen with the finer particles entirely removed takes place creating conditions like natural gravel treatment which is stablished against high velocities. Whereas in artificial gravel treatment, the gravel particles being of uniform size allow no development and create a tendency for the finer particles to work out part way through the gravel treatment and became lodged.

4.18 Figures 4.18-a and 4.18-b show a comparative study of the sand ~~from~~ formation where a gravel pack well is most desired and where it should not be used.

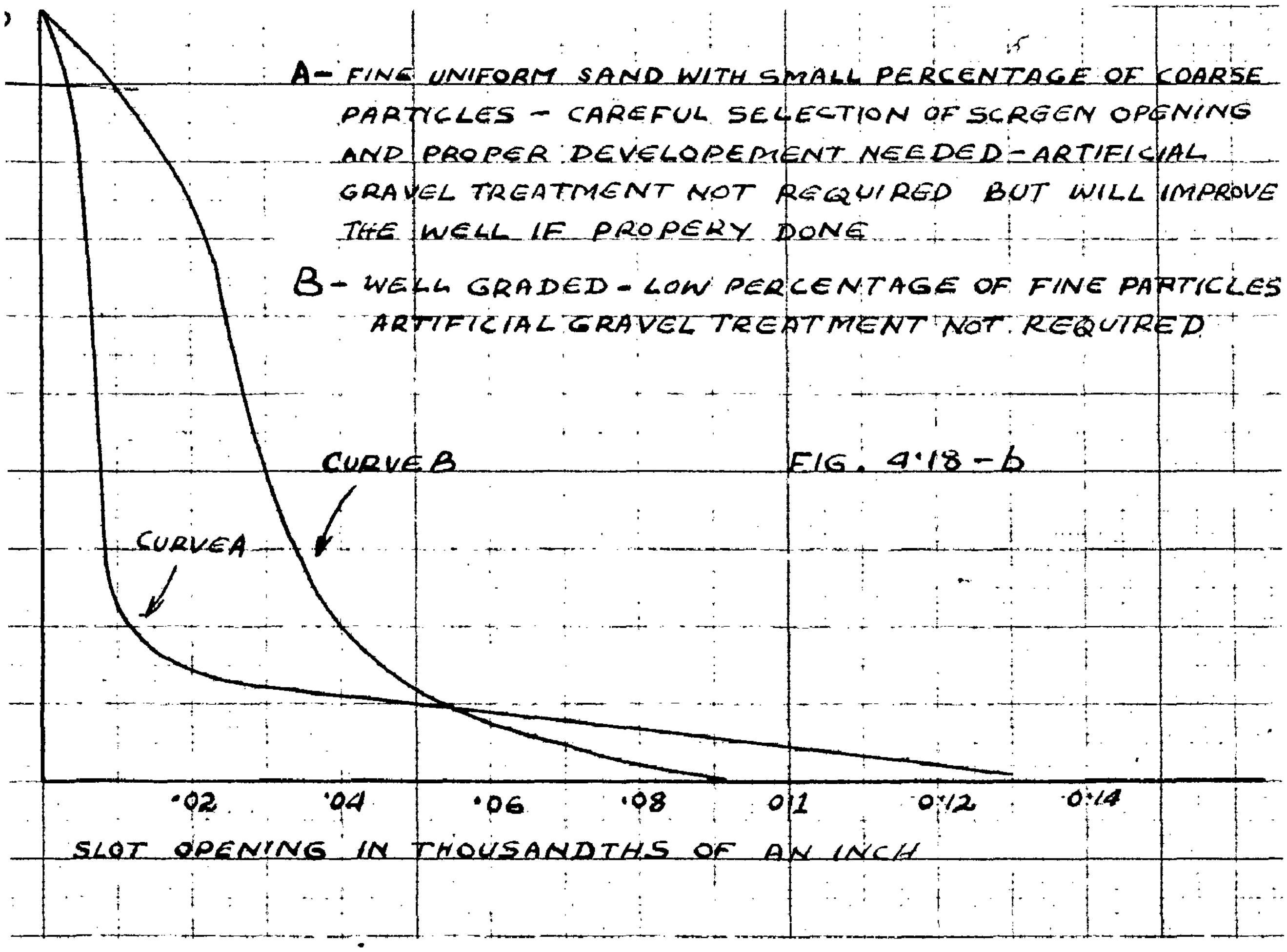

A- FINE UNIFORM SAND WITH SMALL PERCENTAGE OF COARSE PARTICLES - CAREFUL SELECTION OF SCREEN OPENING AND PROPER DEVELOPEMENT NEEDED - ARTIFICIAL GRAVEL TREATMENT NOT REQUIRED BUT WILL IMPROVE THE WELL IF PROPERY DONE
B- WELL GRADED - LOW PERCENTAGE OF FINE PARTICLES ARTIFICIAL GRAVEL TREATMENT NOT REQUIRED
CURVE B
CURVE A
·02
·04
·06
·08
0·1
0·12
0·14
SLOT OPENING IN THOUSANDTHS OF AN INCH

FIG. 4·18 - b

4.19 <u>FACTORS INFLUENCING DESIGN OF AGRAVEL PACK-WELL:</u> The grain size of water bearing strata and the degree of uniformity vary from place to place and even from layer to layer in the same bore. It is, therefore, apparent that neither the same size of shrouding gravel nor the same size of slot openings in the slotted tube will suit all water bearing stratas. There, however, exists a basic relation ship between (a) the size of the slot, (b) grading of the gravel to be shrouded and (c) grading of the water beaning stratum which influence the well performance. Alteration in the effective diameter of the well or reduction of resistance to flow through a well screen also play their part in the performance of a well. All these factors must be carefully taken into account while designing a gravel pack well. However on state irrigation wells in Uttar P-radesh, as far as the author knows, same size of slot and same grading of gravel irrespective of formation size is being used every where which is apprently injurious to the performance and life of wells. Gravel treating is an important phase of a well work and must be co-related with the formation, quantity of water to be produced, cost of the job, etc.

4.20 <u>REQUIREMENT OF GRAVEL SIZE:</u>- Some of the results of studies made in connection with the design of filters in hydraulic structures are also applicable to the design of gravel for gravel pack wells. The essential requirements of a filter, naturally, are :-

I. Its size should be such as not to allow the formation particles to flow through its voids. That is, the effective size of gravel lays betwee certain limits with relation to the effective size of the formation to be treated (1,10) beyond or below which the treatment will not be efficientlyf effective or in other words the uniformity Co-efficient of gravel and the formation are inter-related.

II. Its size should be such as to cause minimum head loss due to surface tension and capillarity (refer para 4.5).

III. Material used in the gravel treatment must be of good quality hard granite like (10), carefully selected as to shape and graded as to size (refer para 4.4-II,III and 4.10).

IV. The shrounding gravel should not have its uniformity Co-efficient more than 3 or also the smaller size of gravel is likely to get seperated from the larger size in an uniform mixture during its passage through the water to the bottom of the well while being poured in (9).

4.21 CRITERIA FOR GRAVEL SIZE TO PREVENT S-AND MOVEMENT:

Terzaghi and others (11,13) made certain recommandations for design of filters (though initially for dams) which were later on confirmed by the U.S. water Ways Experiment Station and U.S . corps of Engineers. According to Terzaghi, the criteria for preventing the formation flow through the voids of filter is

$$\frac{D\ 15\ (\text{filter})}{D\ 85\ (\text{formation})} < 4$$

It means that 15% size of the gravel must be less than 4 times the 85% size of the formation. He further stated that to keep the seepage forces within permissible magnitude.

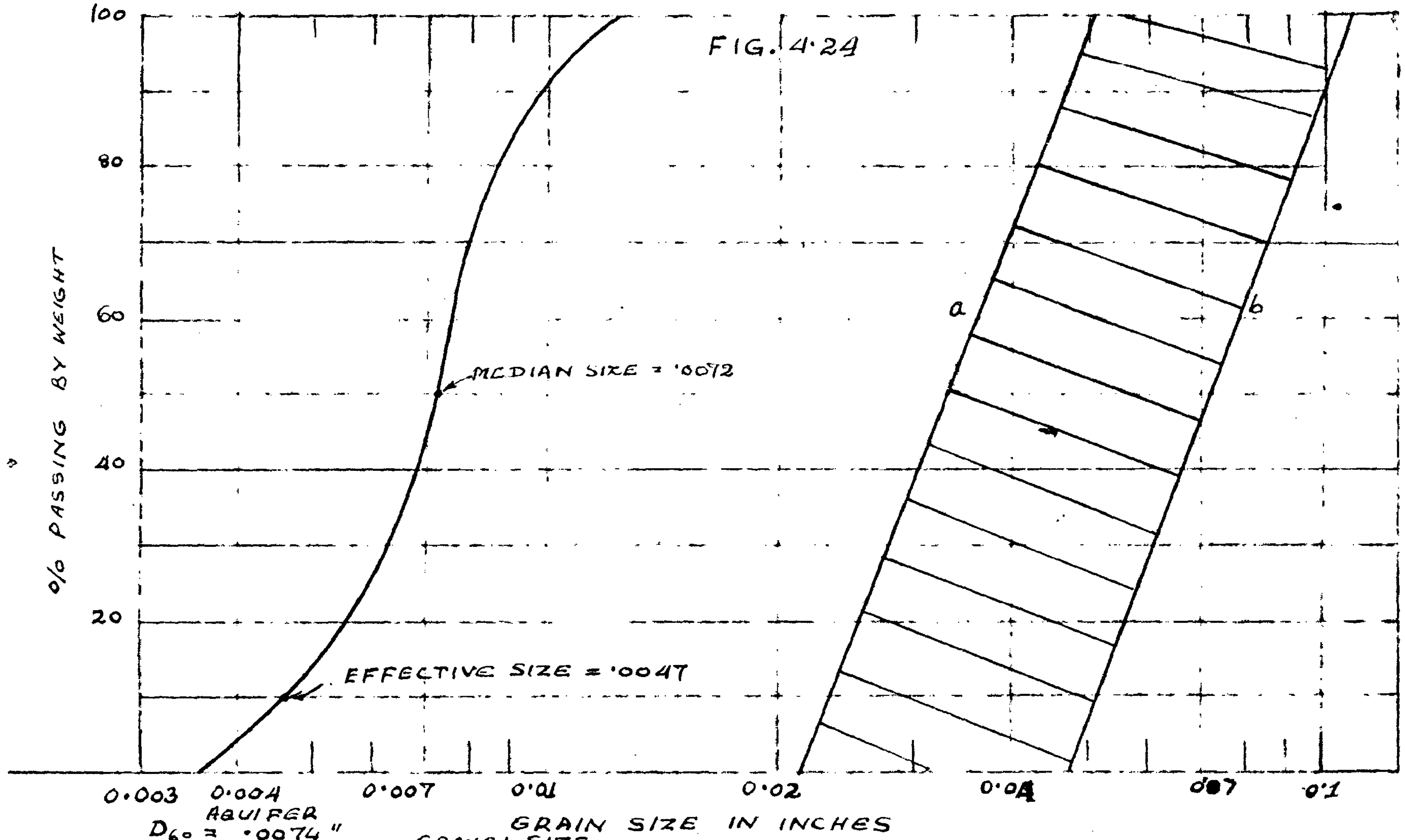
$$\frac{D\ 15\ (\text{ filter })}{D\ 15\ (\text{ formation })} > 4$$

meaning thereby that 15% size of the filter must exceed 4 times the 15% sizes of the formation.

The U.S. Bureau (12) suggested that grain size curve for filter and formation material should be approximately parallel and the envelope material should be packed densely.

4.23 Bertram (14) found that "the minimum critical ration of the 15 per cent size of the filter at the limit of stability is approximately 9". This is applicable where the material is at least 50% compact. In other words if the flow is, say, down ward, each successive layer of material may be composed of particles such that 15 percent size (15 percent smaller than and 85 percent larger than) diametres is 9 times that of the 15 percent size of the layer above. If the above condition prevails and the material is at least 50% compact, practically no imprignation will take place (15). If the ratio is much greater than 9, imprignation may occur. When we take into account the fact that permeability varies approximately as the square of the diameter, it becomes clear that one may go from a fine silt to sizeable gravel in a very few layers.

4.24 The U.S. war Department (16) recommanded that if the uniformity co-efficent of aquifer is less than 2, and the effective grain size is more than 0.30 m.m.,then there does not exists any necessity for gravel packing. If the uniformity co-efficient is less than 2, but the effective size is smaller than 0.30 m.m., then a uniformly graded pack should be provided. To obtain this,



AQUIFER

D_{60} = ·0074"

D_{50} = ·0072"

D_{10} = ·0047"

GRAVEL SIZE

a = ·0072 × 5 = ·036

b = ·0072 × 10 = ·072

CHOICE OF GRAVEL PACK

AQUIFER NO 2 (Ref. para 4·39)

50 percent size of the aquifer material is multiplied by 5 and 10. Points of these values are located on 50% abscissa. Lines are drawn through these points approximately parallel to the average slope of the aquifer gradation curve. These lines are the limits of the most satisfactory pack. If the gradation curve of the pack material falls outside these lines on to the right, the pack material will not stabilise the formation material and should not be used. If it falls outside to the left of these lines then though the aquifer material will be stabilished but the well will be less efficient (fig 4.24).

4.25 For cases, where the aquifer uniformity co-efficient is greater than 2, the U.S war Department has recommanded that:

(a) $$12 < \frac{D_{15}\ (\text{filter})}{D_{15}\ (\text{formation})} < 40$$

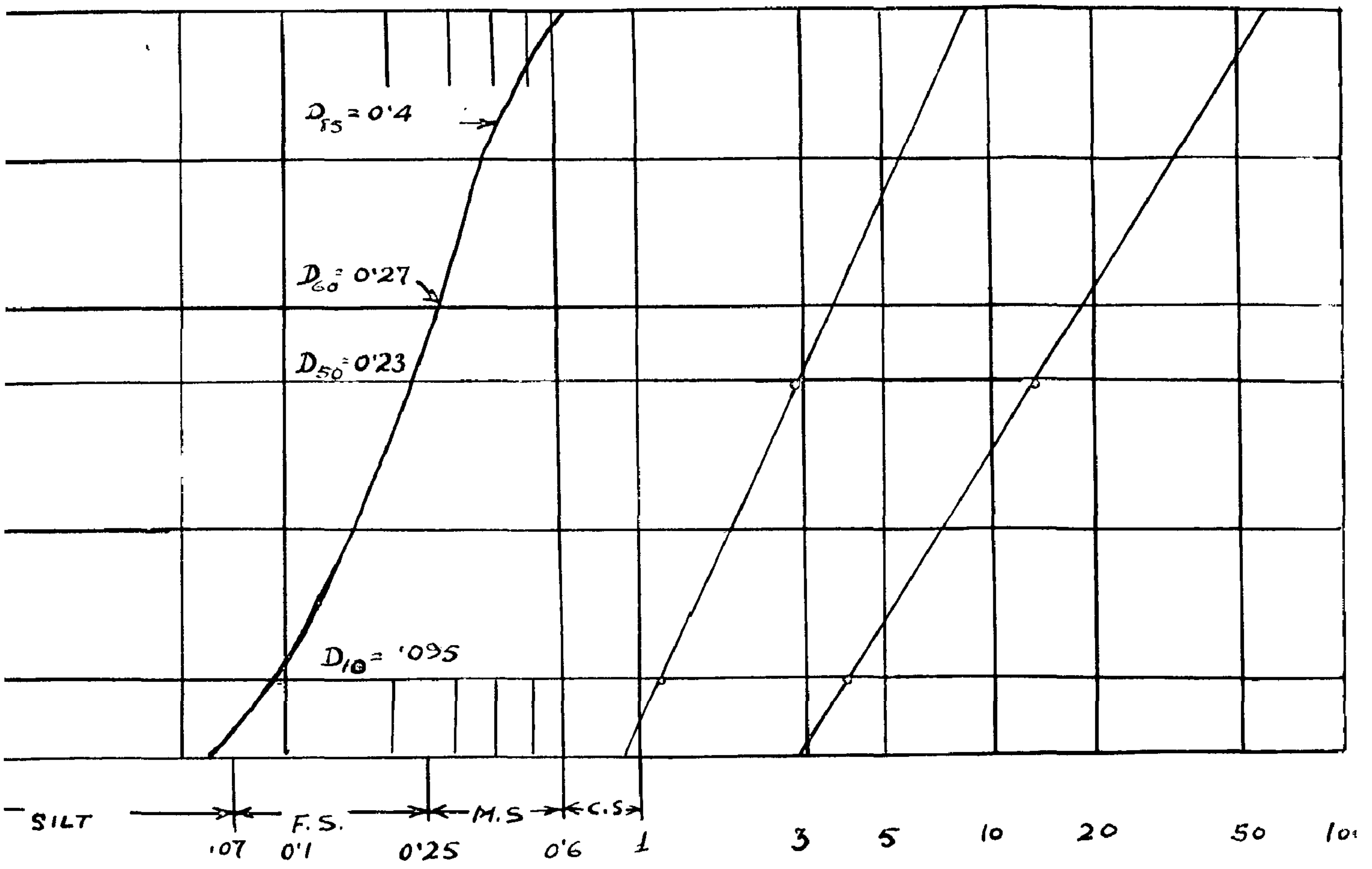
(b) $$12 < \frac{D_{50}\ (\text{Filter})}{D_{50}\ (\text{formation})} < 58$$

To obtain the most satisfactory size of the gravel pack, multiply 50% size of the formation material by 12 and 58, plot the products on 50 percent abscissa. Multiply 15 percent size by 12 and 40 and plot the products on 15% abscissa. These points are then joined with straight lines. The gradation curve of the pack gravel should lie within these lines. (fig.4.26).

2.26 <u>LIMITATIONS OF NON-UNIFORM PACK:</u> On tube-weels a non uniform gravel pack can not be used because:

I. When a non-uniform gravel is poured into a well the different particles will travel the well length with different velocities according to their weights with the result that large void

FIG 4'26



ACK LIMITATIONS

0'23 × 12 = 2'76

0'23 × 58 = 13'34

'095 × 12 = 1'14

'095 × 40 = 3'8

SAND SAMPLE - T.W NO. 30 DAHA GR.
DIST. MEERUT

NON UNIFORM AQUIFER

spaces will be formed below on which the smaller particle will finally come to rest and the aquifer movement can not be, therefore, controlled.

II. Permeability of a non-uniform gravel is less than a uniform one, though it may be placed homogenously. It means less specific yield and higher pumping cost for a desired discharge.

III. Special arrangements and careful placement of the gravel material into the well is required which increases the cost of construction and is not easily possible.

4.27 Due to the difficulties enumerated above an uniform gravel layer is generally used every where. And hence the need of matching the gravel size with that of formation arised.

4.28 A series of tests was carried out in U.P. Irrigation Research Institute Roorkee by Gupta (17) to find out suitable criteria for:

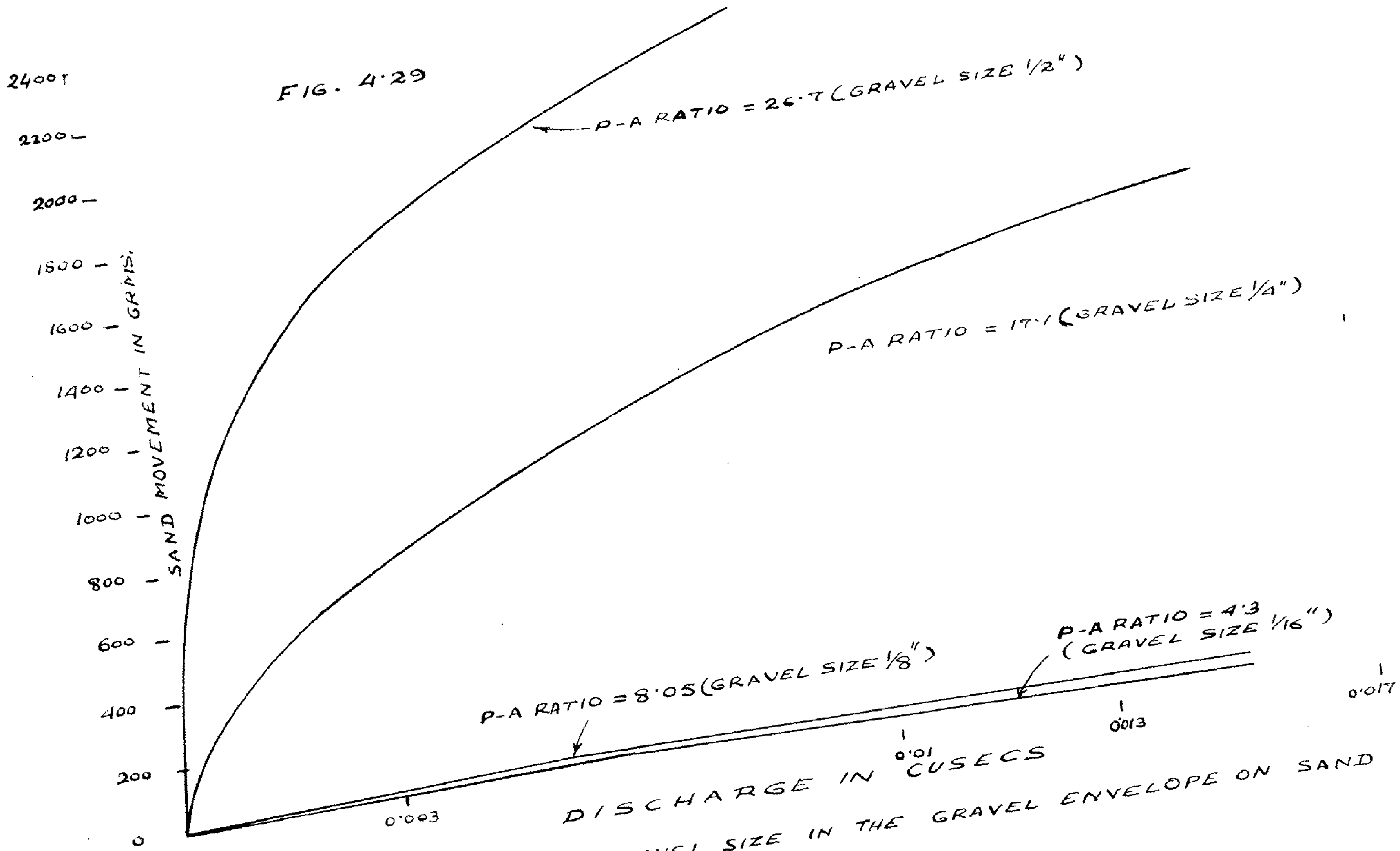
I. The design of a uniform gravel pack for uniform aquifer.

II. The design of a uniform gravel pack for non-uniform aquifer.

4.29 His report on the results of tests is summarised as below.

I. EFFECT OF P-A RATIO: For uniform gravel pack in combination with uniform aquifer, "Y" was found to

FIG. 4·29



EFFECT OF INCREASE OF GRAVEL SIZE IN THE GRAVEL ENVELOPE ON SAND MOVEMENT (REFER - 17) be the maximum stable P-A ratio. Whereas for uniform gravel packs in combination with non-uniform aquifer, 12 was the maximum stable P-A ratio. A higher P-A ratio in the latter case is due to the fact that non-uniform materials forms smaller voids and have a pronounced bridging action which reduces aquifer movement. He also reported that amount of sand movement increases with increase of gravel size of envelope (fig. 4.29).

II. EFFECT OF UNFORMITY CO-EFFICIETS:- Increase in the uniformity co-efficient of the gravel pack, for any particular P-A ratio, reduces the aquifer movement. For low values of P-A ratio, reduction in aquifer movement is less whereas for high P-A ratio, this reduction is much more marked.

III. EFFECT OF VELOCITY: The amount of aquifer movement into the gravel envelop increases with the increase in velocity.

IV VELOCITY LOSS: Size of sand particles is the most significant factor in determining the head loss. Loss through gravel increases where a large quantity of sand is washed into the pack. Surging reduces head loss.

4.30 Similar experiments were carried out in colarodo state University (19) and its recommandations are:

I. If aquifer is uniform i.e.,its uniformity co-effecient lies between 1.3 to 2.0, we can provide:

(i) A uniform gravel pack (1.3<D60/D10<2.0),with P-A ratio = 9.5.

(ii) A non uniform gravel pack (3.0<D60/D10<5.0), with P-A ratio = 13.5.

II. If aquifer is non uniform i.e.,its D 60/D10 lies between 3.0 to 5.0, we can use:

(i) Uniform gravel pack with P-A ratio = 13.5.

(ii) Non-Uniform gravel pack with P-A ratio=17.5.

4.31 It can be seen that results of experiments in para 4.29 and 4.30 are in close appwoximation with each other. There results were arrived at in the laboratories where the conditions very much differ from the actual field in regard with compaction, head, dispersivity, viscosity, velocity, etc. But they can be tried in the actual field on few state wells profitably.

4.32 THICKNESS OF GRAVEL PACK: The thickness of gravel pack around a slotted tube is mainly governed by two following x major factor:

I. Velocity through gravel pack.

II. Ease of development work through gravel pack.

4.33 INFLUENCE OF VELOCITY: Asx previously stated, the velocity of ground water movement is very low. The thickness of gravel pack around the slotted tube increases the effective diameter of the well and for a required rate of pumping, the velo - city of water through the aquifer is reduced further. Once the velocity of water is reduced to a value where it will not carry the sand particles with it, further reduction in velocity is unnecessary. Any further increase in the pack thickness will be deterimental to the well efficiency, because the velocity becomes so low that fine sand is deposited in the voids of gravel and thus choke it. Discussions of para 4.23 show that one can go from fine silt to gravel size in quite a thin layer say four to six inches.

4.34 EASE OF DEVELOPMENT: Development of an artificially gravel packed well is as important as the development of any other type of well. The thickness and the grading of material used in the pack both have considerable effect on the development to bring it to maximum efficiency.

4.35 The hole drilled for a gravel pack well is of larger diameter than the actual slotted tube to be placed in the hole to make room for the gravel for pack. During boring, due to various factors, a thin skin of relatively impervious material is plastered on the walls of the bore. This skin may be formed either due to mud employed in boring by rotory method, or due to recirculation of some amount of clay and fine sand of the formation in the reverse rotory method. Fluid pressure helps in partially plugging the face of the hole by these foreign matters. In cable tool drilling method, the movement of the well casing produce a troweling action that leaves a "slick" of silt and clay on the wall of the hole.

4.36 When the gravel has been placed around the well screen, this impervious skin becomes sand-wiched between the gravel and the natural formation and must be removed by development work to get maximum yield from the well, and hence the importance of the porper thickness of pack.

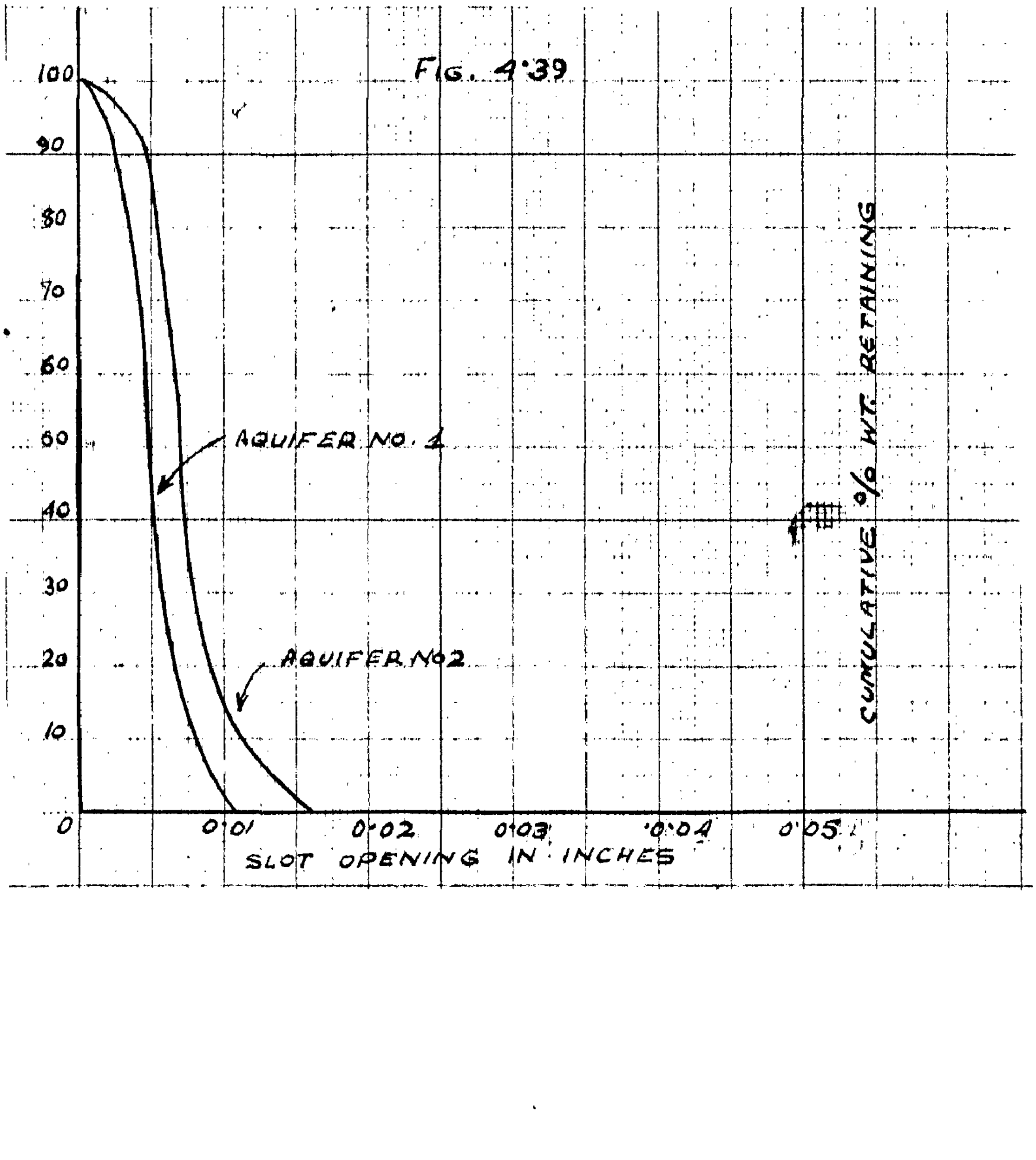


FIG. 4·39
100
90
80
70
60
50
40
30
20
10
0
0·01
0·02
0·03
0·04
0·05
SLOT OPENING IN INCHES
CUMULATIVE % WT. RETAINING
AQUIFER NO. 1
AQUIFER NO 2

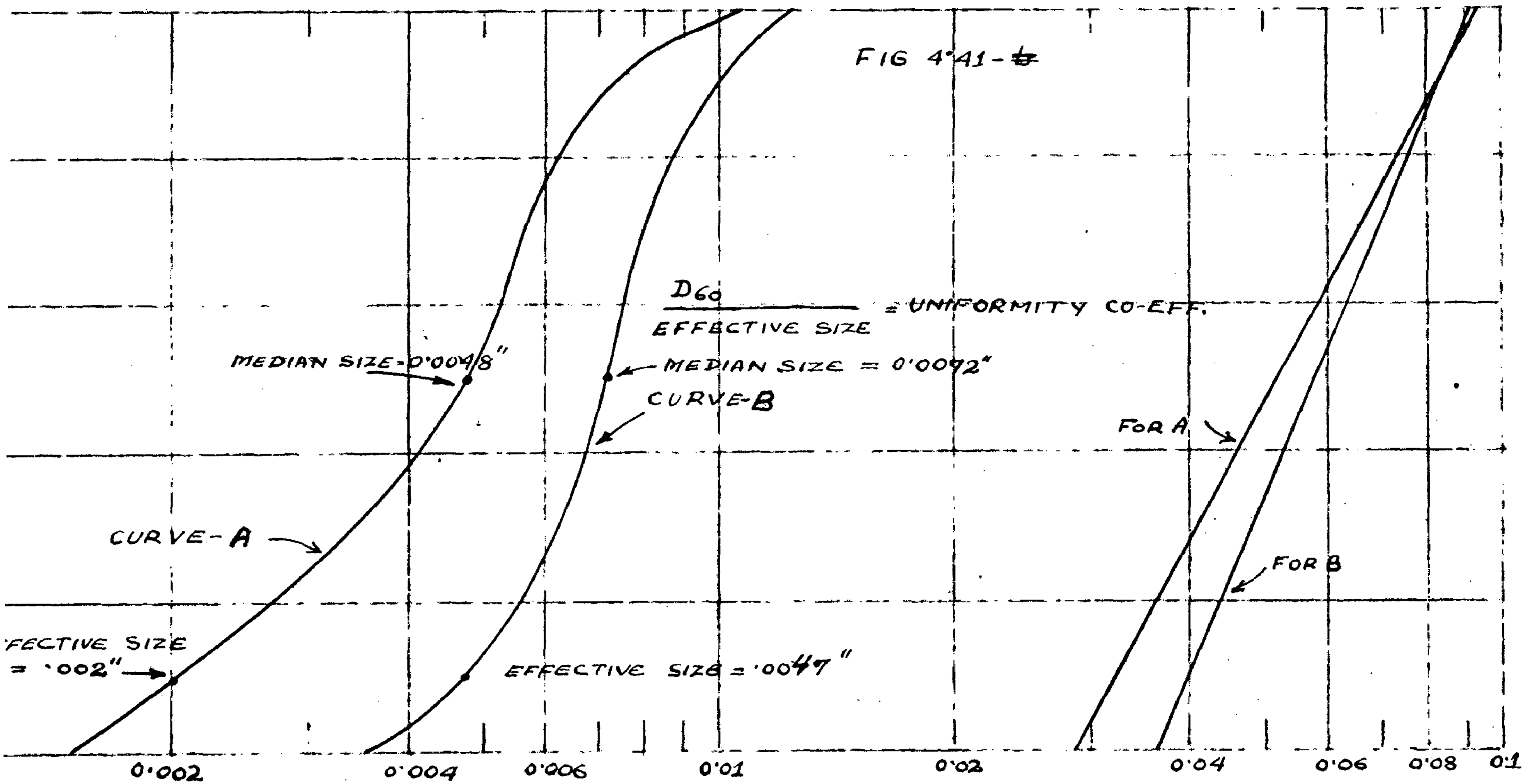
4.37 In a thin pack, undesirable fine sand, silt, clay, etc. can easily be removed during development but it may not stabilise the fine formation properly. On the other hand in a properly designed gravel pack, the permeability is so high that there is more tendency for water to slosh up and down in the gravel envelope rather than to move into or out of the natural formation at places where it may be partially clogged.

4.38 Discussions from para 4.32 to 4.37 naturally indicate that moderate thicknesses of gravel pack are the best choice to undo any damage to the permeability of the formation that results from the drilling operation (21). Now it is a well recognised fact that the annular space required for a properly designed gravel pack varies from three to nine inches, and a pack thicker than one foot is generally a source of trouble from clogging(1).

4.39 DESIGN OF GRAVEL PACK,P-A RATIO: The size of the gravel pack either can be chosen by the method developed by U.S. War Department (16) which has already been discussed in paras 4.24 and 4.25, or it can be chosen by the criteria developed by Gupta (17) and Colarodo State University (19). Examples of the latter method is considered below. Aquifer No.1, is chosen just for sample calculations whereas aquifer No.2. pertanis to T.W.No.15 (appendix B), of Aligarh area. Plots of sand analysis on cumulative percent, weight retaining basis are given in fig.4.39 which reveals that both of the aquifer have a large percentage of fine sand:

Aquifer Material.	Sizes in Inches.			Uniformity Co-efficents	Uniform or Non-uniform.
	D_{10}	D_{50}	D_{60}		
No. 1	.002	.0048	.0054	2.2	Non-uniform
No. 2.	.0047	.0072	.0074	1.55	Uniform.

FIG 4·41-b



GRAIN SIZE IN INCHES

CHOICE OF GRAVEL PACK

AQUIFER NO. 1 = A

AQUIFER NO. 2 = B.

4.40 Since aquifer No.(1) is non-uniform, in order to provide a uniform gravel pack, the P-A ratio is chosen to be 11 which gives D_{50} of gravel = 0.052". This gravel pack is plotted approximately parallel to the aquifer curve (refer para 4.22) which gives uniformity Co-efficient of 1.8 for the pack (fig. 4.40).

4.41 Plot of aquifer No. 2 in fig 4.40 shows that a very large percentage of the aquifer is very fine and uniform. Effective size is .0047 inch i.e. much less than 0.01" and therefore needs a gravel pack for maximum yield (refer fig 4.39). The median size D_{50} is .0072 inch. Since the aquifer is uniform, therefore, to provide a uniform gravel pack, choosing P-A ratio = 8, gives the D_{50} size of gravel = 0.057 in. The gravel pack is now plotted approximately parallel to the aquifer curve and gives an uniformity co-efficient of 1.57 (fig 4.40). For all sizes of gravel pack, the slot size should be so matched as to prevent at least 90% of the pack material from flowing into the well. In appendix (G) sand analysis of 6 state wells of screen type have been plotted. These wells actually required gravel treatment. Size of gravel pack on the basis of recommandations of U.S.W.D. and Colarodo State University has been designed in the case of State tube-well No. South Loi A (Muzzafarnagar).

4.42 <u>LENGTH OF GRAVEL TREATMENT:-</u> The gravel envelope is provided to cover up the perforated portion of the screen. The envelope should be carried upward until the entire screen has been covered and a few feet above to counteract the future settlement possibilities. Gravel treating to the static level or the surface should not be carried out as it does not serve any purpose and simply increases the cost. Gravel treatment carried

4.43 GRAVEL-PLACEMENT: Placing of gravel in the pack around the well is as important as its proper grading. There are, broadly speaking, two types which are widely used:

(I) Ordinary Gravel wall typo,

(II) Stablisod Artificial Gravel Type.

4.44 ORDINARY GRAVEL WALL TYPES- In this method a casing having diameter to accommodate the permanent screen and the required thickness of the gravel pack is sunk to the bottom of the well and cleaned out. Then screen is lowered to the bottom and centred and then properly graded gravel is fed in the annular space around the screen till whole of its length is covered by gravel. While the gravel is being fed in, the casing is slowly raised so as to carry from 6 to 10 feet of gravel between the screen and the casing. This method of placing gravel is positive and is commonly used where the formation is comparatively coarse. The development of this type of packing is carried by over pumping only. The pumping first is started at a low rate and then increased gradually to a value which is higher than the pumping rate of the permanent pump.

4.45 STABLISED ARTIFICIAL GRAVEL TYPE:- When there is no coarse material and the formation is uniformly fine, the stabilised artificial gravel treatment is resorted to because it is the only method to extract maximum yield from such formations free of sand. In this method the gravel is placed in the same way as in ordinary wall type except that treatment is developed as it is placod. Slight surging is done simultaneously to keep the settling gravel treatment free of sand. After the gravel has been placed so as to cover the whole perforated tube, the well is developed in a regular manner. The idea for light surging is to supply the formation with enough gravel to build up a treatment several inchos thick around

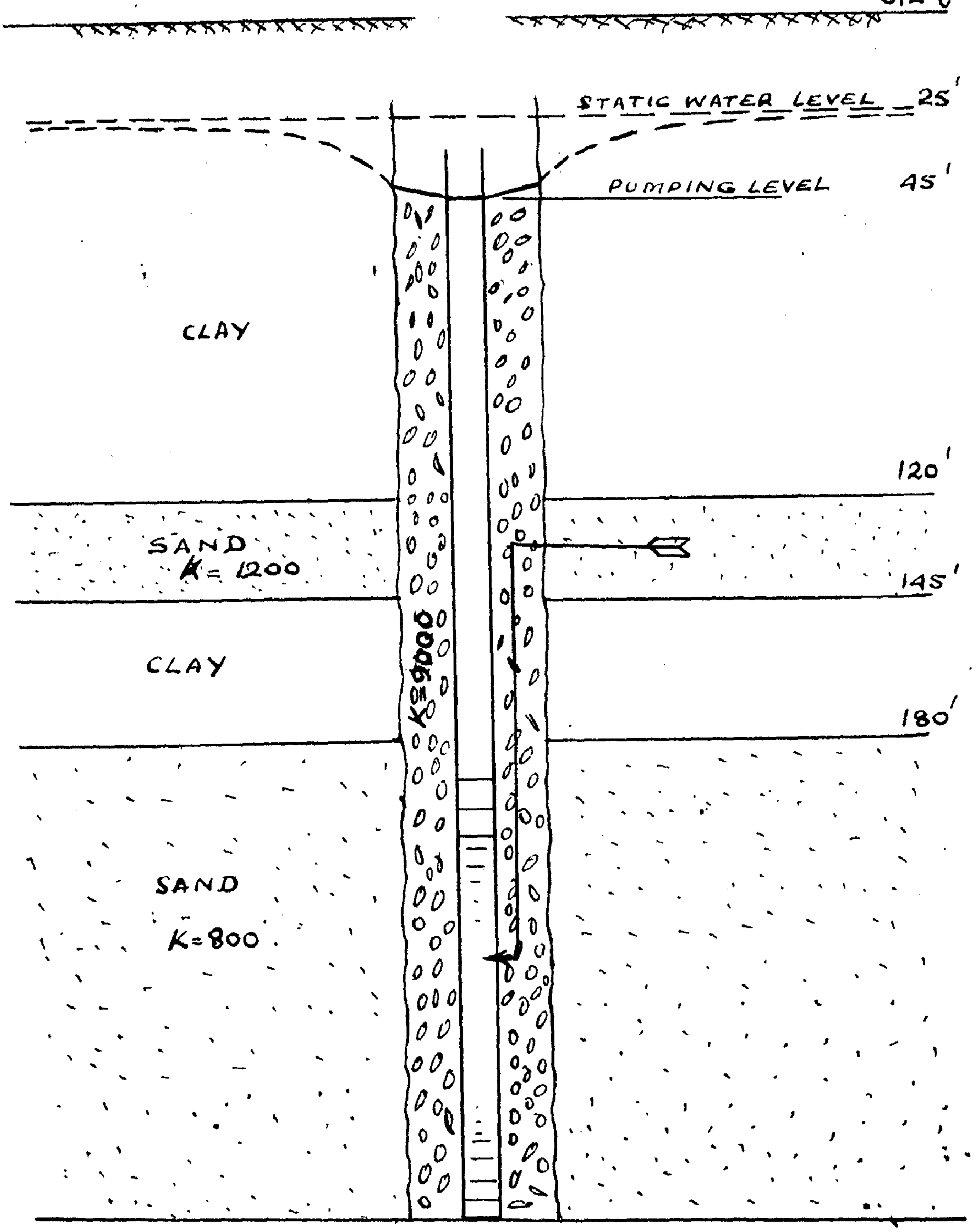
around the screen in order to "stabilize" it.

4.46 SEFE METHOD FOR FEEDING THE GRAVEL:- Small feed pipes or down spouting must be used whenever possible. In this method, the pipe is placed near the bottom of the well with the gravel being fed slowly and evenly until it has filled around the screen to a verticĂl height of 4 or 5 ft. Then the gravel pipe is raised about the same hight and feed is continued. If due to some circumstances, shovel feeding is necessary, then shovelling must be done slowly and evenly so as to avoid seperation of particles and thus maintain the uniformity ratio. Plenty of time must be allowed for each shovol full to settle. The track of the gravel level must be kept at all times.

4.47 LENGTH OF SLOTTED TUBE: Having fixed the size and the slot width (refer para. 4.41) in accordence with the assortment of formation and the sizo of the gravel, the length of the pipo can be calculated as to have velocity of entrance within permissible limits i.e., 0.1 ft.per second. Some authors are of the view that an open area oqual to the suction area of the pump to deliver certain quantity of water will be enough and may bo placed at tho bottom of the gravel treated hole. The water from the upper formations will trickle down to the bottom through the annular gravel pack and will be picked up there by the pump. But this notion is completely wrong and if worked will lead to erronous results as the vertical downward flow through the pack is very insignificant and contribute little to the overall discharge. An example solved below will lead to this conclusion very clearly. Field figures have been chosen to have better understanding.

4.48 Fig. 4.48 shows a gravel pack well 250 feet deep bored by a rig and have bore diometor of 27 inch. A 6 in.slotted tube is

FIG. 4'48



SCREEN FOR BOTH AQUIFERS IS NECESSARY

lowered centrally in the bore and let the slots be locatod at the bottom. The annular space left for gravel packing is:

$$\frac{\pi}{4} \times \frac{1}{144} (27^2 - 6^2) = \frac{\pi}{4} \times \frac{1}{144} \times 33 \times 21$$

$$= 3.78 \text{ sq.ft.}$$

Let the permeablility of the gravel pack material be 9000 g.p.d. per sq.ft. which is approximately equal to the permeability of materials which are generally used for gravel treatment. Head causing the vertical flow is

$$45-25 = 20 \text{ ft.}$$

The water from the upper strata will flow downwards through a distance of 60 ft. and then will enter into the screen which is placed at the bottom of the well.

The hydraulic gradient under which the vertical flow takes place is $= \frac{20}{60} = 0.33$

According to Darcy's law

$$Q = K \times i \times A.$$

Where Q = discharge in gallons per day

K = Permeability in g.p.d. per sq.ft.

i = Hydraulic gradient.

A = Area in square feet.

$$\therefore \quad Q = 9000 \times 0.33 \times 3.78$$

$$\doteq 11.220 \text{ g.p.d.}$$

$$= 7.8 \text{ g.p.m.}$$

These calculations assume that the gravel column is completely clean and open, which is not likely the case in actual practice.

4.49 Approximately, the upper sand having a permeability of 1200 g.p.d. per sq.ft. and with a screen section of 20 ft. locatod from 125 ft. to 145' will yield about 70 g.p.m. Thus about only

10% of the potential yield of this strata can flow down through the gravel envelope under the conditions of this example.

4.50 Above calculations, demonstrate the greater advantage of properly placing the section of the well screen to correspond with the depth of strata that are capable of yielding substantial quantities of water to the well. We should therefore, contemplate no important contribution to yield from vertical flow through the gravel envelope.

4.51 <u>CHOICE FOR ORIENTATION OF SLOTS:</u> Studies recently conducted in Irrigation Research Institute, Roorkee, show that other things remaining same discharge through vertical slots in more than horizantal slots (21). But through horizantal slots there was lesser suction of sand (23). These experiments were conducted without gravel pack. Since a well designed gravel pack eliminates the possiblility of x sand movement, therefore, author feels that vertical slots will be definitely advantageous in a gravel pack well. On state wells in U.P., both horizantal and vertical slots are being used. Performance of vertical slots with gravel pack needs investigations as to arrive on a definite conclusion.

4.52 <u>CHOICE FOR FIXED SIZE SLOTTED TUBES:</u> As previously discussed, it is best to have the uniformity co-efficient of gravel pack as near unity as possible. But it should be less than 2.0 in all cases generally. This immediately fixes the slot size indicating that 10% of the gravel may pass out from slot openings. The gravel size in turn is determined by the formation size. Any deviation from it will either reduce the well efficiency or will not stablise the formation. Therefore, the pipes having fixed slot openings must be utilised on places where they are technically desired. Ignoring these facts, makes an ineffecient well. While choosing the slot size, the strength of the perforated tube must also be taken into account.

4.53 On state irrigation gravel pack wells, tubes of fixed slot sizes 1/16 in. to 3/32 in. are generally being used every where irrespective of the quality of aquifer or the gravel. Gravel used is also of one size only. This practice is obviously injurious to the efficiency and life of the wells (refer para 4.19 and 4.41). The practice, as revealed by Survey (refer appendix B), has resulted into:

I. Sand discharge, frequent break-downs and increased cost of repairs which were sometimes very heavy.

II. Continuous fall in discharge. On the wells surveyed, the average fall in discharge is 2,500 G.P.H. per year (appendix B). The cost analysis (app.A) shows a loss of Rs. 242.00 approx.per well per year for a gravel well, for average running period of 2,100 hours per year.

<u>SUMMARY:</u> In order to have efficient gravel pack wells and to avoid unmatured failures due to sand discharge or fall in discharge, the following steps are recommended for future guidance:

1. Sand analysis of each aquifer layer must be done in each case and correctly interpreted (refer para 4.21), 4.39 to 4.41).
2. Gravel size should match the formation size for high effeciency and stabilisation of aquifer (refer para 4.24, 4.30 and 4.39).
3. For minimum head loss through the screen, the factor $\frac{CL}{D} > 6$ (refer section II of Chapter III).

4. Development should be thorough to minimise the losses (refer para 4.30 to 4.38).

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C H A P T E R - V

TECHNIQUES FOR IMPROVING PERFORMANCE OF SICK WELLS.

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CHAPTER - V.

5.1 INTRODUCTION: So far from Chapter I to Chapter IV latest design aspects only were taken into consideration for constructing a good tube-well for:

I. preventing un-matured and early failures and

II. improved efficient performance

No discussion was made of the trouble which they give during their life.

Though a tube-well can be constructed as much efficient and durable as the prevailing circumstances and the developed techniques well permit but still they fall sick many times during their long serviceable life. And if no proper care is taken in time to restore their vigour, then their productive capacity rapidly falls and from the point of view of economy they can then be classified as partially failed or failed wells. In the irrigation department of U.P.Government, these wells whose discharges are less than 20,000 G.P.H. are called partially failed or unproductive wells. Since the Tube-well Irrigation Scheme is a commercial are therefore, any reduction in yield of a well should ~~require~~ draw keen attention and special efforts to improve upon.

5.2 Many State Wells, as can be seen from the survey reports (appendix B) were quickly reached to the stage of partially failed wells. Since most of the wells in the area were discharging sand in large or small quantity, efforts were made to stop the sand discharge somehow or other. The cause of depletion of supply was naturally attributed as the consequences of sand discharge. But the behaviour of a sick well which has properly been designed for a sand free discharge is totally different and distinctive.

5.3 SICK WELLS: The wells in which the draw down increase faster than in other wells in the vicinity and when they loose productivity are termed as sick-wells. The increased draw-down increases the pumping lift, i.e., more work for the existing pump with a lesser discharge and loss of pump efficiency, the operational cost goes on increasing as the time rolls and and the profit falls. Such situations are obviously uneconomical to permit and can not be allowed to exist.

5.4 CAUSES OF SICKNESS: Chief causes of making a well sick and reduction of its yield are:-

I. Sanding off (a condition in which the productive zones are burried in sand).

II. Coarser layers are sealed off by the fines in the formation.

III. Development of obstructions such as growths, deposits and incrustation in the screen perforations and formations.

5.5 Sanding off can be ascertained by taking sounding and sludging can remove this defect. Defects given in para (5.4 -II,III) generally occur and both chemical and mechanical treatments are employed to remove them. Some times a reduction in the rate of pumping is also recommended.

5.6 REDUCTION IN RATE OF PUMPING: The chemical balance of the ground water is upset by changes in temperature, pressure and flow rate induced by pumping and by pressure difference occuring across the screen openings. This causes the dissolved substances to deposit on and around the openings. A rate of reduction will naturally retard the process of incrustation but actually this is no solution of the problem specially for commercial wells.

5.7 CHEMICAL TREATMENTS: To ~~xxxxxxx~~ dissolve or dislodge clogging materials or incrustation on the screen or in the sand surrounding the screen, chemicals such as acids, chlorine and sodium hexametaphosphate may be added to a well. Acids are to be used only where the metal of the screen will not be affected by them. Some of the acids to be used with different metals are given below:

Acids.	Metals.
(a) Brass or Bronze.	Muriatic acid.
(b) Iron.	Nitric acid.

Acid treatment of the wells has already been discussed in details in chapter III.

5.8 REJUVENATING OF WELLS BY CHLORINATION: Previously acid treatments as discussed above were considered to be sufficiently effective in curing sick wells. But special care was required to handle them as they x were very active and dangerous. The quest for better chemicals, therefore, persisted. Recently chlorine (1,2,3,4,5,6,7,8,9) has come in wide use for restoring the well supply than acids. Chlorination of wells is extremely effective when used specifically for the elimination of bacterial growths that clog well strainers, the areas immediately adjacent to strainers, the pump bowls and the piping leading to the surface. By this method it has sometimes been possible to restore the original figure of yield from wells where the ground water level has not much changed (1) Chlorine mixed with water makes hypochlorous acid which attacks calcareons deposits (2). The chlorine, therefore, has got more general application in reclaiming wells than is commonly supposed (3).

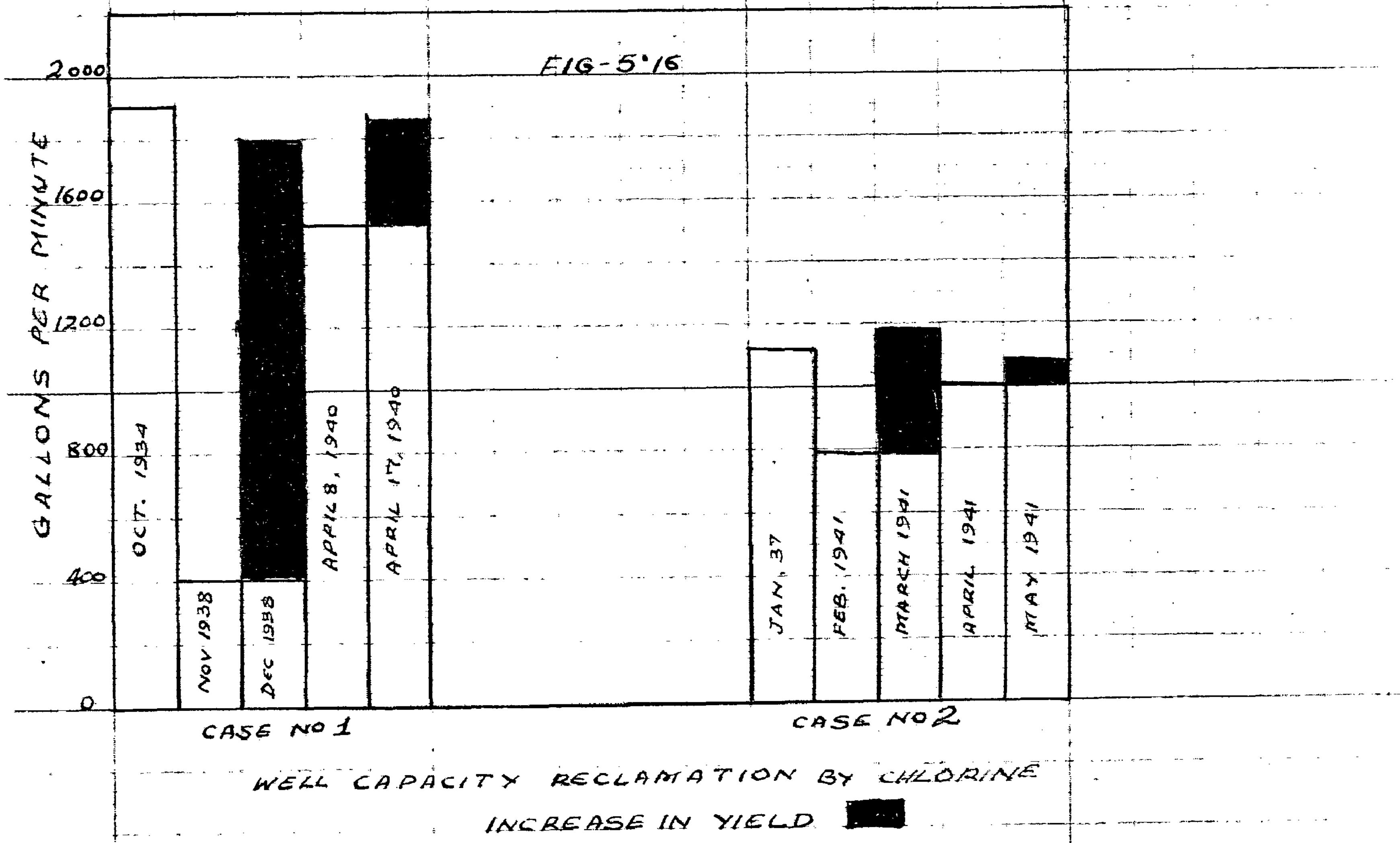
5.9 PROPERTIES OF CHLORINE FOR WELL TREATMENT: Chlorine is about 2.5 times heavy as air at normal temperature and pressure. Chlorine is neither inflammable nor explosive, but it is very corrosive in presence of water. It should therefore, be handled carefully. It is relatively expensive.

5.10 BACTERIAL GROWTH: Water slimes, or organic deposits, usually consists of mucilaginous mixture of capsulated bacteria. Iron and manganese present in the water tend to favour the growth of iron and manganese micro-organisms popularly lumped together under the designation "Crenothrix",(4). These iron and manganese bacteria and some times aluminium bacteria together with high forms of micro-organisms which may abound in water itself, tend to choke the openings of screen and other water handling equipment.

5.11 FURTHER EFFECTS OF PRESENCE OF IRON AND MANGANESE SUBSTANCES:

Besides, promoting bacterial growth, the commenest form in which these metals occur is in the reduced State, as ferrous bi-carbonates or manganous bi-carbonate. These divalent bi-carbonates are Colourless Compounds which exist only in solution and are quite oftenly found in deep well waters (4). Another form of secondary origin and which is applied almost entirely to iron, is in the form of suspended, insoluble higher oxide formed by corrosion of well screen and casing by aeration of water containing ferrous bi-carbonates.

5.12 ACTION OF CHLORINE: Chlorine readily attacks the enzym system which is extremely vital to growth of bacteria and thus destroy it (5). The di-valent carbonates of iron and manganese are oxidised in presence of chlorine and is removed by subsequent settling and filteration.



WELL CAPACITY RECLAMATION BY CHLORINE

5.13 POINT OF APPLICATION OF CHLORINE: The Chlorine in the form of gas or liquid is introduced at the bottom of the well. When applied at this point, Chlorine comes in immediate contact with the sand and gravel surrounding the screen, the screen, the pump and by diffusion with the piping above the pump. The wells are pumped while the Chlorine is being fed in and then allowed to stand for 12-24 hours for thorough soaking by well - Sometimes assisted by slight surging. This practice forces the chlorinated water into the sand and gravel surrounding the screen. When the wells are heavily treated with chlorine, it should be followed up by dechlorination with sulphurdi-oxide and flushed before replacing in service.

5.15 PRECAUTIONS: Overdozing of chlorine in any one operation must be prevented. Chlorine injection can be repeated if the situation so warrants. The pH value must not be allowed to fall below 4 in any case otherwise the screen may be got damaged due to action of hydro-chloric acid.

5.16 ILLUSTRATIONS: Improvement in yield and efficiency of wells has widely been reported in U.S.A.Technical Literature. The effectiveness of chlorivation is well demonstrated by following few examples:

(1) The capacity of two wells of University of Illinois, U.S.A.,(6) reduced to 25% and 45% of the original capacity. Acid treatment could not improve the capacity materially. Afterwards chlorine was injected which improved the capacity of wells upto 90%.

(2) Case history of a well (1) which was constructed in 1934 is shown in figure 5.16. Within 4 years, its capacity became so low that it was considered as useless. But alternate

treatment with chlorine and flushing improved the yield very near to its original capacity.

5.17 Chlorine treatment as discussed above, has been proved to be relatively an inexpensive means of improving the wells, ~~and~~ pump capacities and overall efficiency of the plant. It may, sometimes, be supported by acid treatment. The cost in most cases will be found to be less than the cost of pulling the pump and the period of shut down is also likely to be comparatively shorter. It should however, not be used without determining the trouble to be remedied.

Chlorine treatment has so far not been tried on sick state irrigation wells. In appendix B, it will be seen that there is a large number of slotted wells whose yields have gone down sufficiently without any visible cause. These are good cases for chlorine treatment.

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5.18 <u>CALGON TREATMENT:</u> Besides acid treatment, chlorination of wells was found to be an effective agent for improving the performance of sick wells, and specially in cases of acute organic growth. Apart from bacterial growth, frequently the fall in capacity of a well is caused by plugging of screen or the water bearing strata around the wells with minerals deposited from water, with natural clays, silt, iron oxide or calcium carbonate along with iron bacteria and slime forming organic growth. To meet this problem, a glassy phosphate named CALGON (chemically - Sodium hexa - metaphosphate) has been developed (10,11, 12). Calgon treatment is useful in two ways.

I. It helps new wells to produce at the maximum output consistent with practical limitations of draw down.

II. It helps in rehabilating old wells whose productive capacity has fallen.

5.19 <u>ILLUSTRATIONS:</u> Successful treatment of sick wells by Calgon has widely been reported in U.S.A.technical literature and its use revived many old and sick wells. Out of many examples the following few typical examples clearly demonstrate the effectiveness of Calgon treatment.

A well in Baltimore, U.S.A. (11) whose specific capacity dropped down from 225 g.p.m. to 150 g.p.m. in one year was treated with Calgon and the Capacity increased to 275 g.p.m. without increasing the draw-down. Similarly, the output of a ten year old well was increased from 220 g.p.m. to 330 g.p.m. the original discharge of the well, after Calgon treatment (11).

5.20 <u>PROPERTIES OF CALGON:</u> Calgon contains at least 67% P_2O_5 and is produced by a thermal process from soda ash and grade phosphoric acid. In 1 p.c.solution its pH value is 6.7 to 7.0

and is therefore mmm neutral. It is easily absorbed on the metal surfaces and them oxides and salts.

Ex 5.21 DISPERSIVE PROPERTY OF CALGON: Most important and the fundamental property of Calgon is itsp pronounced ability to disperse finely divided metal oxides and salts including calcium carbonate, clays and similar materials which are commonly found in ground water. Some more materials (10) which are dispersed by K Calgon and are subsequently removed from the wells are listed below:

A morphous Silica, Hydrated Ferric oxide, Iron Carbonate, Calcium phosphate, Magnesium Silicate, Calcium Sulphate, Ferric-oxide, Magnesium Silicate etc.

5.22 Some minerals like Calcium Carbonate and Iron oxide or Carbonate can easily be dissolved and subsequently removed by acid treatment but most of the above (para 5.22) minerals found dissolved in water will not respond to acid treatment. Calgon, however, has been found very effective in such cases.

5.23 ACTION OF CALGON: The action of Calgon is manifold as described below:-

(1) It forms a thin film of phosphate over the metal surface which prevents corrosion.

(2) It prevents the precipitation of Calcium Carbonate or lime scale.

(3) Complexing and dispersion ability combined with above properties prevents precipitation of dissolved iron in iron bearing water.

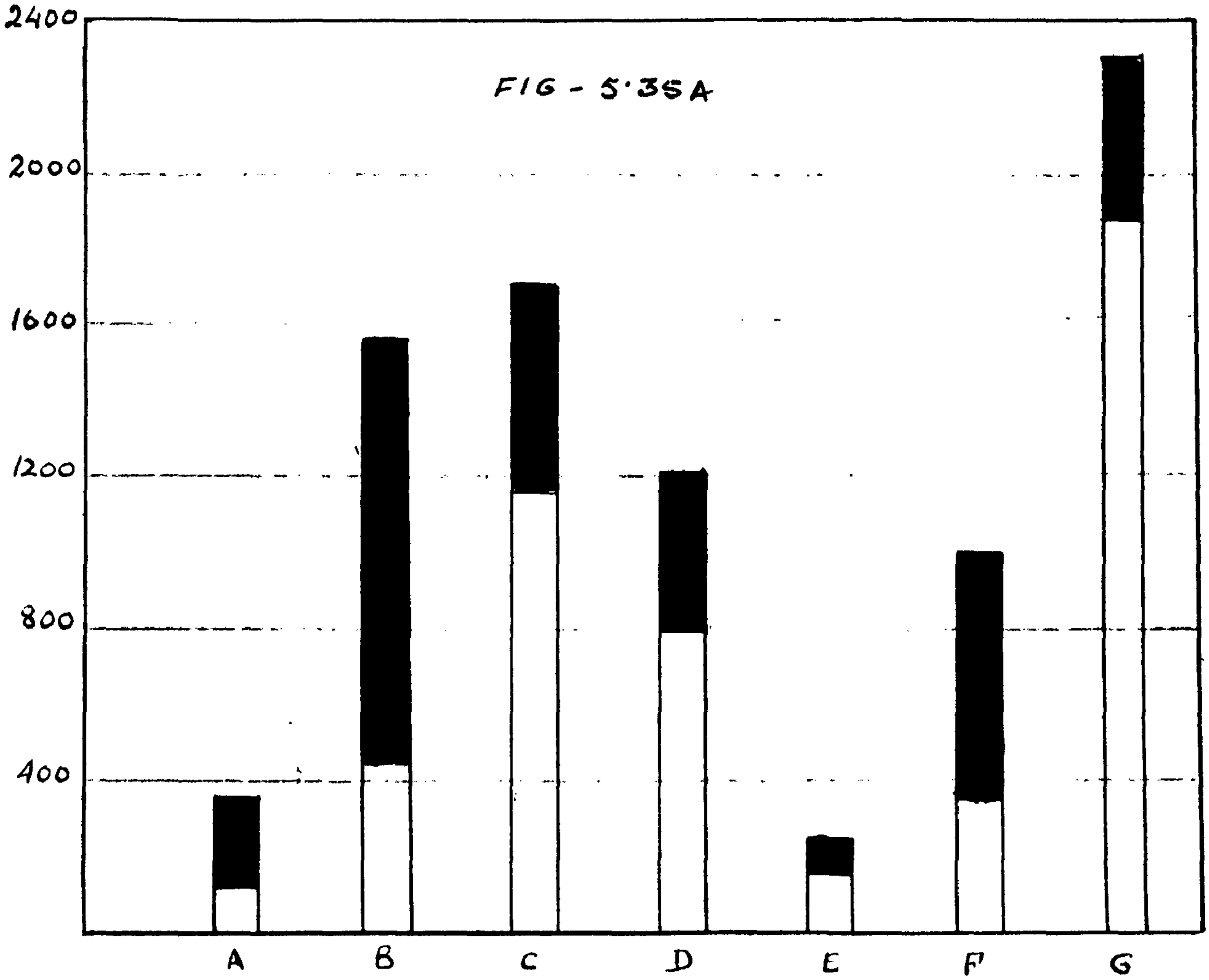
5.24 METHOD OF CALGON TREATMENT: With the pump and all other equipment left in place, the chemical is poured into the well under stationary conditions and ~~xhn~~ is allowed to remain there ~~f~~ from 24 to 48 hours. During this period the pump is turned on and off 10 or 12 times at equal interval for Surging. If surging is not possible then chemicals are to be left in the well for about a week. Surging is done in such a way that water is raised to the ground level and then is allowed to drop back into well. This action forces the calgon solution out into the formation through well screen.

5.25 The resultant churning action helps the Calgon to loosen and disperse the deposits on the screen and in the formation. Calgon is comparatively a slow acting chemical substance than acid and therefore require a larger contact period for its complete action. The entire process is repeated again and again till no further improvements are observed. Generally two or three charges are sufficient. The well should be thoroughly flushed before putting into service.

5.26 QUANTITY: Generally 15 - 30 lbs of Calgon with one or two lbs.of hypochlorite are used for each 100 gallons of water in the well casing under static conditions. Hypochlorite is added to accelerate the removal of organic growths from the well(10,11).

5.27 ADVANTAGES: Glassy phosphate is harmless to either metal or concrete (9) during the short contact periods employed in treatment, whereas the acid attacks the metals quickly. Therefore in Calgon treatment, the wells can be cleared leaving the pumping equipment in place without any risk of its being damaged. This results in reduced labour expenses and shut-down.

5.28 DEVELOPMENT OF WELLS: Since the glassy phosphate is capable of dispensing and consequent removal of clay and other



EFFECT OF VIBRATORY EXPLOSION ON PRODUCTION OF WELLS

KEY LETTER	WELL-NOS	YEAR DRILLED
A	C.J. DAILEY 60A	1930
B	BARSTOW 2	1930
C	COLTON 13	1934
D	WALNUT PARK 9	1947
E	MC VINE 1	1948
F	BEAUMONT 4A	1949
G	WHITTIER 12	1951

DARK PORTION SHOWS THE IMPROVEMENT

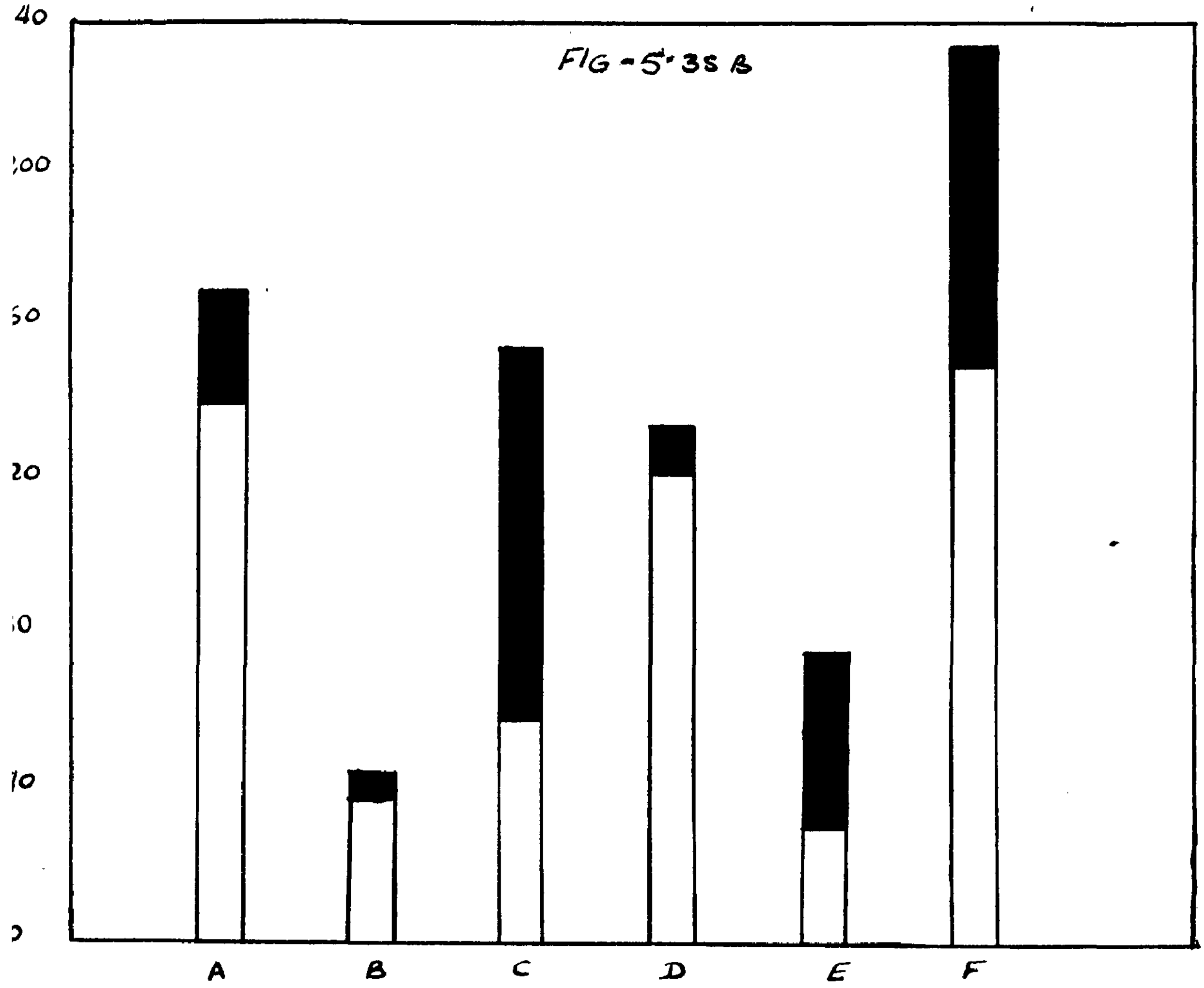
substances, it can naturally be used for initial developments of new wells.

5.29 FREQUENCY: Calgon treatment is not a permanent cure and has to be applied as the situation requires. But, however, it has been reported that periodic cleanings are more convenient and useful than attempts to maintain well capacities by continuous glass phosphate feeding.

5.30 SCOPE: From data of wells of Uttar Pradesh (Appendix B), it will be seen that yield of many slotted and strainer wells have decreased considerably. No action to improve their discharges could be taken except of fitting a high capacity pump in most cases. In such cases where draw-down has also gone down and pump sets are in satisfactory conditions, Calgon Treatment is expected to increase their yeilds.

5.31 MECHANICAL METHODS: The wells can also be redeveloped by mechanical methods such as surging, air lift, dry ice treatment and swabbing. Swabbing accompanied by air lift has been found to be most effective mechanical treatment (13). But all these methods are slow and costly. The shut down period is generally large and the results are short lived.

5.32 FURTHER RESEARCHES: Mechanical methods as described in para 5.31 above were not found effective and were quite troublesome. Chemical treatment is chiefly aimed only at the specific type of growth and is only mildly effective on incrbstation. It is short lived also. Special care has to be taken in using strong acids as they are very destructive to the metal of pump and well casing. Better methods for improving the performance of sick wells were, therefore, constantly searched out by experts.



EFFECT OF VIBRATORY EXPLOSIVE ON DRAWDOWN

DARK PORTION REPRESENTS REDUCTION IN DRAWDOWN AFTER VIBRATORY EXPLOSIVE TREATMENT

KEY LETTER SAME AS IN FIG 5'

5.33 EXACT REQUIREMENTS: From discussions in preceeding paras, it will be seen that exact requirements and object for redeveloping the wells were-

I. Maximum Efficiency with minimum cost.

II. Minimum danger to the equipment and well structure.

III. Minimum shut down period.

5.34 DEVELOPMENT OF VIBRATORY EXPLOSIVE-NEW TECHNIQUE:

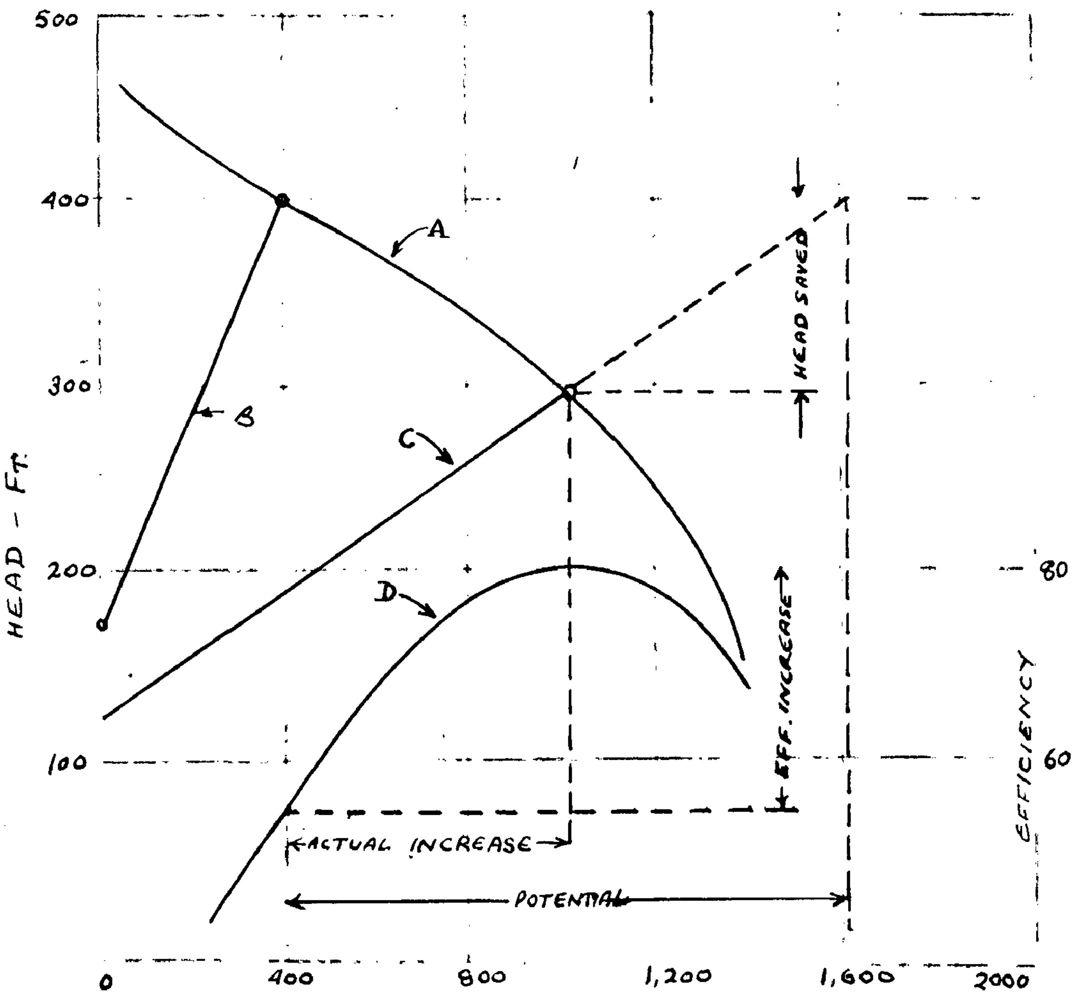
Besides mechanical and chemical treatments of wells, explosives were sometimes used for improving the performance of wells. But the results were not satisfactory due to its high power. In some cases, casings gave way under high power developed by detonators or P.E.T.N. and the wells completely failed. However after long search and continued efforts a technique has recently been developed in U.S.A. for revitalizing of wells by vibration explosive methods (14,15,16). Original objection of the vibratory explosive method was redevelopment of sick wells by removing incurstation or fines at perforated areas but it has also been found very effective on new wells for initial development work.

5.35 ILLUSTRATIONS: A summary of benefits to 7 wells located in Southern California, U.S.A. is given in fig. 5.35A. Improvements in draw-down of these wells is shown in fig.5.35B. The improvement in production and draw-down for Beaumont well 4A is given in fig. 5.35C.

A study of these tests reveals the effectiveness of vibratory explosive method which permits the pump to operate near designed efficiency.

5.36 PRINCIPLE: The vibratory explosive method is based

FIG - 5'35C



IMPROVEMENT ON OPERATON BY VIBRATION EXPLOSIVE

A = HEAD CAPACITY; B = DRAW-DOWN BEFORE TREATMENT

C = DRAWDOWN AFTER TREATMENT', D = EFFICIENCY

THE SPECIFIC YIELD WAS 1'61 GPM AND 6'55 GPM BEFORE AND AFTER TREATMENT. HEAD SAVED = 103 FT., INCREASE IN EFFIC. 45% ACTUAL INCREASE IN YIELD 630 GPM. AND POTENTIAL 1232 GPM

THE WELL TESTED WAS BEAUMONT 4A. U.S.A.

on controlled release of explosive power of P.E.T.N. The heat of explosion of 1ft. i.e. approx. 2 gn. of PETN is 2880 Cal.Explosives are commercially available as low as one ninth this strength (320 Cal.per gm). Thus if the period of explosion is increased to 5,000 times and its power decreased to 1/9th, the energy of explosive can be reduced to $\frac{1}{45,000}$ that of PETN. In this fact lies the safety of the vibratory explosive method for use on tube-wells.

In vibratory explosive method, a series of closely spaced, small charges are fixed at accurately timed intervals with the result that a series of small blows continued over a large period of time is obtained.

5.37 <u>BUBBLE CYCLE ACTION:</u> Cole (13) studied the effects of large quantities of gas generated by under water explosions. The results of these investigations were released to public in 1948 only due to security restrictions. He observed that gas bubble forces the water to move away so rapidly that are after flow, or enlargement of the bubble beyond its normal capacity is produced. But the hydro-station pressure surrounding the bubble easily over-come the inflated condition and the bubble soon contracts. Bubble expands and contracts 10 times, on an average before the energy is substantially exhausted as a single expansion. Thus for each shot water is forced in and out, through the perforations of screen of well, 10-times for each shot. When one cycle is completed, second series of shot is fired and so on. The time can be varied by means of special firing mechanism.

5.38 <u>QUANTITY OF EXPLOSIVE:</u> It is always possible to compute the safe amount of explosive for redeveloping the wells by the following two well known formulas-

I. Bursting strength of pipes in which the explosive is to be used can be ascertained by Barlow's formula.

II. Pressure developed by an explosive confined in a tube with water both outside and inside the tube can be calculated by Franklin E.Roach formula.

Thus just amount of explosive to dislodge or break-up any incrustation or other material and wash them free by means of bubble cycle can easily be calculated.

5.39 METHOD: Special explosives are spaced on various loads to correspond with the perforated area. This prepared firing string is suspended inside the well d casing while the pump is still in position. After the firing line is fixed, when the explosives are opposite the perforated area, the charges are detonated at pre-determined intervals by a special firing mechanism.

The explosion produces a continuous series of shock waves of relatively long duration that may be used in various casings, yet are powerful enough to shatter and dislodge obstructions in the perforations and or in the surrounding formation.

5.40 USE IN DEVELOPMENT OF WELLS: In newly constructed wells, vibratory explosive opens new passages because of re-arrangement of aquifer which would have otherwise not been available by ordinary development methods. It has been reported (15,16) that yield from the wells developed by vibratory explosive method was more than ordinarily developed wells in the same aquifer.

5.41 FACTS AND ADVANTAGES OF VIBRATORY EXPLOSIVE METHODS:-

The following advantages have been well established of this method:-

1. Definite and prolonged improvement can be achieved safely.
2. Proper use of explosives makes them least expensive.

It requirod the shortest shut-down time and producos minimum disturbance to the pumping unit.

Indiscriminate use of the method is very dangerous to property and can ruine the well.

The vibratory explosive method which has been claimed to be very effective in revitalising the old wells is a patent method held by M/s. Norman A.McLeod California,U.S.A.

5.42 SUMMARY: From the survey data (appendix B), it was found that almost no efforts of any kind were made to improve the yield of old wells anywhere nor any such efforts are being taken at present. It appears, that this happened due to the fact that engineers were always pre-occupied with the problem of stopping sand discharge which appeared on a majority of wells,whether they were strainer type or gravel pack slotted type wells.Depletion of supply was generally attributed to the defect of sand discharge. A list of working wells which wore surveyed and on which chlorine injection method or calgon treatment can be adopted profitably is given in appendix C.

5.43 Vibratory explosive method though extremely effective and efficient will not be possible on agricultural strainer type wells due to its very fragile nature. These strainers will not with-stand the explosive force and the well will be lost.

5.44 As and when improved technique of well construction is adopted and sand free wells are made, then these techniques are bound to play their important role and will thus save many unmatured failures of sick wells.

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S U M M A R Y

A N D

R E C O M M E N D A T I O N S

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PREVENTION OF FAILURES OF TUBE-WELLS AND STUDY OF RECENT TECHNIQUE OF CONSTRUCTION FOR IMPROVED PERFORMANCE

SUMMARY AND RECOMMENDATIONS

After independence, there has been a phenomenal quick growth both in agricultural and industrial fields in our country. The demand of water both for agriculture and industry has increased manifold. At present, due to near exhaustion of economic sources of water like lakes, reservoirs, rivers, etc., it has become imperative to harness ground water by tube-well pumping. Prevailing rates of water supply from tube-wells in Uttar Pradesh state do not compare favourably with canal rates hence its use has not developed so much as it should be. The main reasons for the scheme to be costly as revealed by the survey data (refer appendix 'B') collected by the author are:

1. Average life of wells in this state is very low. It is 16 years as compared to 40 years approx. in U.S.A. in similar formations.

2. There is a high incidence of unmatured retirements and failures (fig. B_2 in App. B). The maximum life of strainer well as observed from data collected is 25 years while the average life is only 16 years. (refer App. B).

3. Due to sand trouble on almost every well, the maintenance cost as well as the energy cost is considerably increased with loss of revenue. Revenue from an ordinary screen well is Rs. 300/- per year as compared to Rs. 953/- per year from a good designed and better screen well (refer appendix A).

The cost of water from tube-wells can naturally be reduced substantially if the above shortcomings are somehow overcome. This can be achieved, if, every component of a well is properly analysed and scientifically designed. As a matter of fact, a well is just like any other engineering problem and calls for considerable attention to it. A proper study of formation in which a well is to be located and the design of well structure according to formation qualities, hence, is very important.

On correct interpretation of physical and chemical properties of formation, depends

1. The yield from the well
2. future troubles and
3. Life of a well

For a scientific good design, the following tests (refer chapter I) should invariably be carried out which were not done hithertofore.

1. Sieve test for each layer of formation to determine the physical properties of sand and consequent design of screen structure.
2. Permeability test to determine the capacity of well.
3. Chemical test to determine the quality of water and consequent selection of proper material and subsequent preventive operation (refer chapter V).

Besides the above tests, a careful pre-study of water table contour map is also very helpful in correct location of wells (refer para 2.24 to 2.26). Such a map immediately reveals that:-

1. A crammed and steeply rising water table contours indicate a fine formation not suitable for well construction.
2. Flat contours show a coarse formation.

The exploratory tube-well organisation of Govt. of India, it is learnt, has started preparing such maps but these have not yet been published.

The pre-study of water-table and ground contour map may also in some cases help in averting an un-necessary expenditure on operational cost (refer para 2.28 to 2.30)

When the above formalities have been completed, the question arises whether the well should have a straight screen or should be gravel pack. Though a gravel pack well gives a better performance, but its use should not be resorted to in every case as its construction is costly and calls for better technique and special costly tools. Its construction should be confined to those cases in which the requirements as detailed in para 4.16 to 4.18 are not fulfilled. Tube-wells should generally be constructed of straight screen type.

Whether a well is to have a straight screen or slotted tube screen, the proper design of both types of screen is very essential for better performance and longer life. The selection of a proper screen is a very complicated problem as discussed in detail in chapter III. The following requirements should, however, be satisfied by a good screen.

I) It should be strong enough and should provide a maximum open area (refer para 3.32, 3.39, 3.40, 3.47, 3.48, 3.145 and 3.149). The velocity of flow into the screen should not be more than 0.1 ft. per sec.

II) For minimum head loss, compromise should be made in screen factors C, L and D such that $\frac{CL}{D} > 6$. (refer para 3.25). The value of factor $\frac{CL}{D}$ can be worked out only when value of C is known for which further investigations are needed as described in chapter III.

III) The screen openings should be of such size and shape that it would respond to surging and development works (refer para 3.41, 3.153, 3.154) so that maximum amount of water is transmitted with least head loss. V types of openings are most suitable.

IV) The material selected for the screen should have 40 to 50 years of useful life. It should not deteriorate by corrosion and chemical action of ground water or by acids used at a later stage (refer para 3.106, 3.120 to 3.122). A well designed and corrosion resistant costly screen is definitely a better investment (refer appendix A).

In gravel pack wells, the general trouble is of sand discharge, chocking of strata by fine sand movement and consequent fall in yield and heavy maintenance cost. In order to avert these troubles and to have a prolonged life of wells, the following recommendations are made.

1. Sand analysis of each strata should be carried out (refer para 4.21, 4.39 to 4.41).
2. Gravel size should match the formation size (refer paras 4.24, 4.30, 4.39)

3. Screen should be designed for minimum head loss. The velocity of flow of water into the screen should not be more than 0.1 f.p.s. And if the value of factor C is known then $\frac{CL}{D} > 6$ (refer section II of chapter III)
4. Well should be developed thoroughly for minimum formation loss and maximum yield (refer para 4.3 to 4.38).

After completion of constructional and development work of a well, a draw-down test (refer para 2.36 to 2.46) should be made. By this method it is possible to seperate the two components of losses (1. formation loss, 2. structure loss). Any such subsequent test will reveal the source of trouble and remedial measures to remove it can be chosen correctly (refer chapter V).

Though a well can be constructed sufficiently efficient but still during their life they fall sick and their productive capacity falls (refer para 5.1). As soon as the yield of a well falls and its draw-down increases in comparison with other wells in the vicinity, with no apparent cause, then chemical tests should immediately be carried out to determine the nature and extent of salts present in the water. In order to restore their full vigour, the following methods have been suggested.

1. In case of bacterial growths or the presence of Iron and Manesum carbonates in water, chlorination of wells as described from para 5.7 to 5.17 will be useful.
2. When minerals and salts as detailed in para 5.21 are present in water, calgon treatment as described from para 5.18 to 5.29 will be most effective.

3. In case of severe sickness where the well does not responds to above two treatments, vibratory explosive method as discussed in paras 5.34 to 5.41 may be employed. It must be noted, as stated previously, that the present screen structure - agricultural strainer - of state wells is not strong enough to withstand the shocks of vibratory explosive method. Instead of improving, the well will be completely ruined. Therefore, this method should only be tried where strong screens as discussed in chapter III have been installed.

In short the recommendations for constructing a tube-well of good design and consequent improved performance can be summarised as below:

1. Contour map of the area where a well is to be located should be prepared first.
2. Sieve test for each layer of formation should necessarily be done to determine the design of well structure.
3. Permeability test should be carried out to determine the well capacity.
4. Chemical test should be carried out to determine the quality of water in order to select proper materials for well structure.
5. Straight screen type wells should generally be constructed. Gravel pack wells should be undertaken only in cases where conditions as described in para 4.16 to 4.18 are not satisfied.
6. For minimum head loss, the velocity of flow of water into the screen should in no case be more than 0.1 f.p.s.

7. As far as possible V type openings of screen should only be chosen for better efficiency

8. Better screen materials, such as stainless steel, Everdur or Monel material should be chosen where the situation so warrants.

9. After completion of constructional work, a draw-down test shall be carried out carefully and results so obtained shall be kept carefully throughout the life of well. It will be most helpful in determining future sources of troubles.

10. As soon as a well fall sick, scientific investigations must be done and treatments such as chlorine injection or calgon treatment should be carried out for more severe cases and where the screen is sufficiently strong, vibratory explosive treatment which is a sure treatment may be tried to revive the well.

APPENDICES

_A_P_P_E_N_D_I_X_"A"_

Cost Analysis of a Higher Priced Screen V/S A Cheap Screen (Now in Use)

The cost analysis of a good designed well screen and a cheap screen has been based on two important factors from the point of view of economy:

I. average life span of the well

II. average fall in discharge.

Thus if there is very little fall in yield from the well over its entire life and also if the life span is greater than, naturally, the well working will be comparatively cheap.

Improved average life: The average life of agricultural type strainer well and slotted well as revealed by the survey (refer table of general performance of Agri. strainer well ~~and slotted well~~ appendix B) is only 16 years ~~and years respectly~~ at present. The average life of screen and slotted wells in U.S.A. where surveyed in late forties was found to be 30-35 years. From the developments being made at that time, definite opinion was expressed by many tube-well experts in a panel discussion in U.S.A. in 1946 (1) that there was no reason why the life of a screened well could not be increased to 50 years. Since then knowledge of better materials and science of well has greatly increased, hence it is supposed that the average life must have been greatly improved upon. by now. The average life of wells at present is 16 years and the maximum life is 25 years which is very poor. Our aim for the future wells must, therefore, be to make them serviceable for about 50 years. For cost analysis purpose, however, being on very conservative side, a moderate life span of 35 years only has been taken.

Fall in discharge of Agri. strainer type well: Survey revealed (refer appendix B) that on failed wells, the average fall in discharge per year in 16 years was 6,300 g.p.h. The whole of this fall in discharge can not, possibly, be attributed to defects in screen only because the behaviour of formation also comes into picture. Let 1,500 g.p.h. fall in average discharge be due to formation clogging and the rest 4,800 g.p.h. average fall in discharge be due to screen defects such as incrustation, clogging, corrosion and sand pumping.

It will be seen that from a good and strong screen, it would have been possible to resotre the original supply and in some cases even more by treatments like calgon and vibratory explosive methods provided the reservoir did not deplete. But due to very fragible nature of the strainer screen employed at present, these methods can not be employed.

Also from a good screen, let us assume an average fall in discharge of 1000 g.p.h. The net fall in discharge due to only cheap screen will, therefore, be 3800 g.p.h. Expressing in tabular form:

I. Average fall in discharge from a cheap screen well per year (from survey data)	- 6,300 g.p.h
II. Average fall in discharge due to reasons other than screen	- 4,800 g.p.h
∴ Average fall in discharge from a cheap screen	- 4,800 g.p.h
Anticipated average fall in discharge per year from a costly screen well	1,000 g.p.h.
∴ Comparative average fall in discharge from a cheap screen (now in use) well	3,800 g.p.h.

OPERATIONAL COST - CHEAP SCREEN

(a) Depreciation cost: From sinking fund method, the amount of depreciation allowed per year is given by the formula:

$$D = \frac{r(V-V_1)}{(1+r)^n-1}$$

where r = rate of interest per year

V = Original cost

V_1 = Salvage value

n = number of years.

Assuming salvage value to be nil in both the cases of cheap screen and higher priced screen, the formula reduces to

$$D = \frac{rV}{(1+r)^n-1}$$

Capital Cost V

For a 33000 g.p.h. well 300 feet deep,

cost of boring, set and other items approx.	= Rs. 15,500/-
Cost of strainer now in use 100 ft.@ Rs.25/- per ft.	= Rs. 2,500/-
∴ Total capital cost V of a strainer well	= Rs. 18,000/-
Life of strainer well n	= 16 years.
Rate of Interest	= 4%

∴ Rate of depreciation of a cheap strainer well per year

$$D_{ST} = \frac{.04 \times 18000}{(1+.04)^{16}-1} = \frac{720}{0.87}$$

= Rs. 830 per year

(b) Electricity cost: The present tarrif of electricity in the state is Rs. 150/- per year per B.H.P. installed plus n.p. 5.5 per unit consumption.

B.H.P. required for a 33000 g.p.h. well to work against a head of 50', assuming a pump efficiency of 60%.

$$= \frac{33000 \times 10 \times 50}{60 \times 60 \times 550} \times \frac{100}{60}$$

$= 13.9$ say 14 B.H.P.

∴ Fixed electricity changes for

14 H.P. @ Rs. 150/- per H.P. = Rs. 2100.

Units consumed for 4000 average running hours for 28,200 g.p.h. discharge (average fall in discharge from a cheap screen was 4,800 g.p.h.)

$$= \frac{14 \times 746}{1000} \times 4000 \times \frac{28,200}{33000}$$

$= 3.6 \times 10^4$ kw Hr.

Cost of units consumed

5.5 n.p./kw Hr. $= \frac{3.6 \times 10^4 \times 5.5}{100}$

= Rs. 1980.00

∴ Total Electricity charges per year

= 2100 + 1980 = 4080

Say Rs. 4100 per year

(c) Interest on capital @ 4%

= 18000 x .04 = Rs. 720/- per year

(d) Overhead charges including staff per well per year - say = Rs. 800/- per year

(e) Maintenance and repairs per well per year = Rs. 300/- per year

∴ Total operational cost per year (a + b + c + d + e) = Rs. 6750/- per year

Revenue: The average yield is 28200 g.p.h. for 4000 Hrs. running.

∴ Total yield = 28200 x 4000 gallons

The water cost Rs. one for every 16000 gallons

∴ Revenue per year $= \frac{28200 \times 4000}{16000}$

= Rs. 7050/- per year

SAVING

Net saving per year per well = 7050 - 6750

= Rs. 300/- per year

Rate of Return:

∴ Rate of return on capital from a well where a cheap screen has been installed $= \frac{300}{18000} \times 100$

= 1.67 %

OPERATIONAL COST - HIGH PRICED SCREEN

(a) Depreciation cost

Capital cost:

For a 33000 g.p.h. well

300 feet deep, cost of boring, set and other items approx.	= Rs. 15,500/-
Cost of 100 feet good screen @ Rs. 100/- per foot.	= Rs. 10,000/-
∴ Total capital cost V of a good screen well	= Rs. 25,500/-
Life of a good screen well n	= 35 years
Rate of interest -	= 4%

∴ Rate of depreciation of a good screen well per year

$$D_{Sc} = \frac{.04 \times 25,500}{(1+.04)^{35} - 1}$$

$$= \frac{.04 \times 25,500}{2.95}$$

= Rs. 346.00 per year

(b) Electricity cost

B.H.P. required for a 33000 g.p.h. well of 60% efficiency.	= 14 H.P.
∴ Fixed electricity charges for 14 H.P. @ Rs. 150/- per H.P.	= Rs. 2,100/-

<u>Units consumed</u>: In a cheap screen well, the average running hours as revealed by the survey data are 4000 Hrs. per year at a discharge of 28,200 Hrs per year at a discharge of 28,200 g.p.h. Therefore total water pumped during one year

$= 28200 \times 4000$

$= 11.28 \times 10^7$ gallons

But in the case of a high priced screen, the average fall in discharge has been assumed to be 1000 g.p.h. and therefore the average yield will be 32000 g.p.h.

∴ For the same demand of water, the average running hours of a good screen well will be

$$\frac{11.28 \times 10^7}{32000} = 3500 \text{ Hrs.}$$

∴ Units consumed

$$= \frac{14 \times 746}{1000} \times 3500 \times \frac{32000}{33000}$$

$$= 3.56 \times 10^4 \text{ kw Hr}$$

∴ Cost of units consumed

@ 5.5 n.p./kw Hr $= \frac{3.56 \times 10^4 \times 5.5}{100}$

= Rs. 1960/-

∴ Total Electricity charges per year

= 2100 + 1960

= Rs. 4060/-

(c) <u>Saving due to improved head loss</u>: Let by employing a well designed screen and subsequent proper development, the improvement in depression be by 1.5 feet on an average. For an average discharge of 32,000 g.p.h. and 3,500 average running hours, the saving in running cost will be as follows:

$$\text{Rs. } \frac{32,000 \times 10 \times 1}{60 \times 60 \times 550} \times \frac{100}{60} \times \frac{746}{1000} \times 3500 \times \frac{5.5}{100}$$

= Rs. 539/- per year

Say Rs. 54/- per year

(d) Interest

Interest on capital @ 4%

per annum - 25000 x 4 = Rs. 1020.00

(e) Overhead charges: Overhead charges including staff per well per year (less maintenance staff will be required due to lesser troubles), say Rs. 650.00

(f) Maintenance and Repairs: - Cost of maintenance and repairs per well per year (due to good screen there will be less trouble hence less cost) say Rs. 75.00

∴ Total operational cost per well per year (a + b - c + d+e+f

= 346 + 4060 - 54 + 1020 + 650 + 75 = Rs. 6097

Revenue :- It will remain the same as that from a cheap screen well, because the total quantity of water pumped in both the cases remains the same.

∴ Revenue per year = Rs. 7050.00

SAVING: Net saving per year from a properly designed good screen well is 7050 - 6097

= Rs. 953.00 per year.

Rate of Return: Rate of return on capital from a well where a costly screen has been installed is

$$= \frac{953}{25,500} \times 100 = 3.73\%$$

From the foregoing calculations it will be seen that excess profit earned by a high priced and well designed screen per year is

Rs. (953.00 - 300.00) = Rs. 653.00 per year

Rate of return on Rs. 7000.00 is $\frac{653}{7000} \times 100 = 9.3\%$

The capitalised value of the profit earned in 35 years at 4% interest will be

$$953 \times \frac{(1.04)^{35} - 1}{.04}$$

$$= 953 \times \frac{2.95}{.04}$$

= Rs. 70,210.00 approx.

Thus it will be seen that the capitalised value of the excess profit earned by one such well is sufficient to finance two good designed and costly wells within its anticipated average life.

COMPARATIVE STATEMENT OF COST ANALYSIS

6666

Sl. No.	Item	Cheap ordinary screen in uso Rs.	Costly good designed screen Rs.	Net Financial gain from a costly screen per year
1.	Capital Outlay	18,000.00	25,500.00	-
2.	Operational cost per year	6,750.00	6,097.00	653.00
3.	Profit per year	300.00	953.00	653.00
4.	Rate of return on capital outlay	1.67%	3.73%	2.06%
5.	Capitalised value of profit earned by the well	6,450	70,210.00	63760 in 35 yrs

From the above discussions it will be seen that by simply investing Rs. 7000.00 more, we can get a return of Rs. 653.00 mor per year over a period of 35 years i.e. rate of return on an investment of Rs. 7000.00 is about 9.3% which is quite attractive. The overall rate of return from the well is increased by 2.06%. Moreover the net profit earned by a good and well designed screen of a well is Rs. ६३७६०.००.

The rate of return on capital outlay is lower because of the electricity charges which are quite heavy in this state. To make a tube-well scheme popular and more economical, the electricity charges will have to be brought down.

Cost Analysis of loss from a slotted tube type well of ordinary design as in vogue

The slotted well is a very sturdy well. All treatments for restoring the yield can be employed on it and, therefore, its original yield can be maintained over its entire life provided that underground reservoir has not depleted.

From the table of general performance of slotted wells in appendix B (refer page 187), it will be seen that average fall in yield per year per well over a period of 8 years average running is 2,500 g.p.h. for an average 2100 running hours. The loss in revenue due to fall in yield is worked out as follows:

Total loss of gallons of water per year pumping period

$= 2500 \times 2100 = 5.25 \times 10^6$ gallons.

water is sold at 16000 g.p.h. per rupee,

$$\therefore \text{ Loss of revenue } = \frac{5.25 \times 10^6}{16 \times 10^3}$$

$$= 3.28 \times 10^2$$

$$= \text{Rs. } 328/-$$

For pumping out the above quantity of water from the well, the following expenditure has to be incurred:

Operational charges of electricity at 5.5 n.p. per KW Hr

$$= \text{Rs. } \frac{2500 \times 10 \times 50}{60 \times 60 \times 550} \times \frac{100}{60} \times \frac{746}{1000} \times 2100 \times \frac{5.5}{100}$$

$$= \text{Rs. } 86.16$$

Say Rs. 86.00 approx.

Therefore net loss of revenue = 328 - 86

= Rs. 242.00 per year.

Note: The other items of operational cost will remain the same whether yield falls or not.

Since there are very few cases of failures in this type of wells, therefore, they are expected to work for 35 years. And if the fall in yield is not checked then the capitalised value of loss of revenue per year assuming the same average fall over the entire life span of 35 years will be as follows:

$$\text{Capitalised value of loss in revenue} = 242 \times \frac{(1.04)^{35} - 1}{.04}$$

$$= 242 \times \frac{2.95}{.04}$$

$$= 17847$$

Say Rs. 17800/-

For hundred such wells, the loss of revenue in 35 years

= 17800 x 100 = Rs. 17,80,000

The above amount of loss is, obviously, very heavy and justifies the attention which should be paid in designing a proper gravel pack well as discussed in chapter IV of this paper.

Besides the above loss, from a good designed slotted tube-well, depression head will be less and which will result in still better economy,

PREVENTION OF FAILURES OF TUBE-WELLS AND STUDY OF RECENT TECHNIQUE OF CONSTRUCTION FOR IMPROVED PERFORMANCE

APPENDIX "B"

SURVEY REPORT

Data of about 300 state irrigation wells of districts Dehradun, Saharanpur, Muzaffarnagar, Meerut and Aligarh of Uttar Pradesh state was collected and citically examined in order to find out the general performance of tube wells, causes of their early failures and useful life as a result of present method of construction and design. Data of only 180 typical cases - 103 strainer type wells and 77 slotted type wells - has been included in this appendix of the paper.

Method adopted for calculating (1) yield, (2) useful life, (3) average fall in yield and (4) average running hours is as follows:

YIELD: Only the representative yield has been taken in column 5 of the table. This figure generally gives the yield of the well over the period indicated by the previous and subsequent year to it as included in the column. This method gives a sufficiently accurate average discharge for the whole useful life of the well.

USEFUL LIFE: For simplicity, useful life has been calculated by subtracting the year of construction from the year when the last discharge was observed. For example, if the well was constructed in 1952 and the last discharge was taken in 1961, then useful life of the well is 61-52 = 9 years.

AVERAGE FALL IN DISCHARGE PER YEAR: Average of various representative discharges of column 5 of the table except the initial discharge was first calculated. Then this average was subtracted from the original discharge. The resulting figure gives the average fall in discharge. For example, the initial discharge of T.W. No. 26- Meerut group is 31,161 g.p.h. The representative discharges of the subsequent years are

1946	-	28,199
1949	-	27,251
1950	-	24,083
1951	-	22,796
1955	-	20,348
1956	-	17,300

Total of 6 observations - 1,39,977

∴ Therefore average representative yield

per year = $\frac{1,39,977}{6}$

= 23,329 g.p.h.

∴ Fall in discharge per

year = 31,161 - 23,329

= 7769 g.p.h.

say 7800 g.p.h.

The fall in discharges of wells have been rounded up to the nearest higher or lower hundred figure as it is more or less than 50.

AVERAGE RUNNING HOURS: It has been calculated by dividing the upto date hours run of the well by the useful life of the well i.e. by the figure of column 7.

Besides the above information, seperate tables have been prepared indicating the general performances of strainer type and slotted type of wells as regards their average life, minimum life, maximum life, average fall in discharge, running hours, etc. on group and district basis.

FIG.B_1 - It shows the comparative average fall of discharge and useful life of tube wells for districts of Meerut, Muzaffarnagar Saharanpur and Aligarh.

FIG B_2 - It shows the trend of failures of 6" Agricultural type of wells of four above mentioned districts. It will be seen that after 16 years of age, the incidence of failures increased sharply as time rolled on.

FIG.B_3 - and FIG.B_4 - These graphs show the representative discharges of tube wells No.1 South Loi group and No. 24-A North Loi group. These wells were discharging sand in large quantity (refer serial and 62 of append. B). The perforated pipes of these wells were badly corroded in a very short period and large holes were formed (refer fig.3·105) Large quantity of sand, therefore, was pumped out which brought a quick failure of these wells.

FIG.B_5 - The graph shows the performance of slotted wells of the districts surveyed. It shows the trend of fall of discharge over various groups of running period. Since most of the slotted wells surveyeyed are comparatively new, the fall in discharge has not been very substantial. But as the time will roll on the discharges are bound to fall very much.

TABLE OF GENERAL PERFORMANCE OF 6"
AGRICULTURAL STRAINER WIRES

me of District	Average life	Average fall in discharge	Average years Hours Run	Remark.
Abondoned wells				
erut	17	6,200	5,200	Maximum life=25 yrs.
zaffarnagar	15	5,300	5,100	Minimum life= 7 yrs.
hafanpur	13	7,700	2,600	
igarh	18	6,200	3,200	
Total	63	25,400	16,100	
AVERAGE	16	6,300	4000	
Inservice wells				
erut	11	5,000	2,900	Mdaimum life=26 yrs.
zaffarnagar	14	6,800	4,500	
haranpur	11	7,900	3,700	
igarh	-	-	-	
Total	36	19,700	11,100	
AVERAGE	12	6,600	3,700	

DISTRICT - MEERUT

Name of Group.	Nos. of wells examined		Useful life in years		Average fall in discharge G.P.H.		Average yearly hours run.	
	Abondoned.	In Service	Abondoned.	In service.	Abondon-ed.	In ser-vice.	Abondon-ed.	In service.
MEERUT GROUP.	4	14	55	176	38,900	80,000	18,800	39,600
LOHARA GROUP.	6	3	91	23	14,900	7,000	37,600	9,300
DAHA GROUP.	7	-	115	-	29,300	-	43,200	-
SARDHANA GROUP	7	1	138	4	40,400	4,000	32,600	3,100
BHATIPURA GROUP.	2	-	31	-	20,800	-	9,700	-
BHATIPURA SOUTH GROUP.	3	-	62	-	22,800	-	11,600	-
DAURALA DISTRIBUTORY.	2	-	42	-	22,400	-	7,600	-
BHATIPURA NORTH GROUP.	1	-	21	-	7,100	-	4,000	-
GHAZIABAD GROUP.	2	-	33	-	13,400	-	12,400	-
Total of wells examined:	34	18	588	203	2,10,000	91,000	1,77,400	52,000
Average per Well:	-	-	17	11	6,200	5,000	5,200	2,900

Well Records Examined = 52
Wells abondoned = 34
Wells still in service = 17

<u>Wells still in service:</u>
Average life = 11
Maximum life to date = 25

<u>Abondoned wells:</u>
Average life = 17
Maximum life = 25
Minimum life = 10

DISTRICT MUZZAFARNAGAR

Name of Group.	Nos.of Wells Examined.		Useful Life in years.		Average fall in discharge G.P.H.		Average yearly hours run.	
	Abondoned.	In Service	Abondoned.	In service.	Abondoned.	In service.	Abondoned.	In service.
SOUTH LOI GROUP:	4	4	54	42	24,600	19,400	23,200	20,700
NORTH LOI GROUP:	3	4	57	75	16,700	25,500	14,400	20,600
KAKRA GROUP:	2	1	34	14	5,800	5,800	9,600	4,900
JANSATH GROUP:	3	3	34	37	16,200	30,300	13,500	7,700
Total of wells examined:	12	12	179	163	63,300	81,000	60,800	53,900
Average per well:	-	-	15	14	5,300	6,800	5,100	4,500

Well records examined: = 24
Wells abondoned --- = 12
Wells still in service = 12

Well still in the service:
Average life = 14
Maximum life to date = 26

Abondoned wells:
Average life = 15
Maximum life = 22
Minimum life = 7

DISTRICT - SAHARANPUR

Name of Group.	Nos. of well examined.		Useful life in years.		Average fall in discharge.		Average yearly Hours run.	
	Abondoned.	In service.	Abondoned.	In service	Abondoned.	In service	Abondoned.	In service
SAHARANPUR GROUP:	2	-	26	-	14800	-	5000	-
NAKUR GROUP:	1	-	16	-	7400	-	4400	-
ROORKEE GROUP:	2	1	22	11	16,500	7900	3600	3,700
Total of wells Examined:-	5	1	64	11	38,700	7900	13,000	3,700
Average per well of the group:	1	1	13	11	7,700	7,900	2,600	3,700

Well records examined = 6

Wells abondoned = 5

Wells still in service = 1

WELL STILL IN SERVICE:-

Average life = 11
Maximum life to date = 11

ABONDONED WELLS:-

Average life = 13
Maximum life = 16
Minimum life = 11

DISTRICT - ALIGARH

Name of Group.	Nos. of wells examined.		Useful life in years.		Average fall in discharge G.P.H.		Average Yearly Hours run.	
	Abondoned.	In service.	Abondoned.	In service	Abondoned.	In service.	Abonndoned.	In service.
ATRAULI GROUP:	2	-	34	-	5,800	-	7,500	-
KASGANJ GROUP:	4	-	74	-	31,600	-	11,400	-
Total of wells examined:-	6	-	108	-	37,400	-	3,200	
Average per well:	1	-	18	-	6,200	-	3,200	-

Well records examined = 6

Wells abondoned = 6

Wells in service = Nil.

Abondoned wells:

Average life = 18

Maximum life = 20

Minimum life = 15

Name of District and Group.	Nos. of wells examined.		Useful life in years.		Average fall in discharge G.P.H.		Average yearly hours run.	
	Abondoned.	In service.	Abondoned.	In service.	Abondoned.	In service	Abondoned.	in service.
DIST. MEERUT.								
Bhatipura South Group.	4	-	88	-	31,400	-	17,100	-
Bhatipura North Group.	3	-	47	-	21,400	-	12,100	-
Daurala Distributory.	3	-	57	-	40,600	-	13,800	-
DIST. MUZZAFARNAGAR:								
Deoband Group.	-	3	-	19	~~4,600~~	4,600	-	6,300
DIST. ALIGARH:								
Atrauli Group.	1	-	16	-	1300	-	3,600	-
Total of wells examined	11	3	208	19	94,700	4,600	46,600	6,300
Average per well.	1	1	19	19	8,600	1,500	4,200	2,100

Well records examined = 14
Wells abondoned = 11
Wells still in service = 3

Wells still in service:
Average life = 19
Maximum life todate=19

Abondoned wells:
Average life = 19
Maximum life = 25
Minimum life = 15

TABLE OF GENERAL PERFORMANCE OF 6" SLOTTED TUBE TYPE WELLS

6" SLOTTED TUBE TYPE TUBE - WELLS.

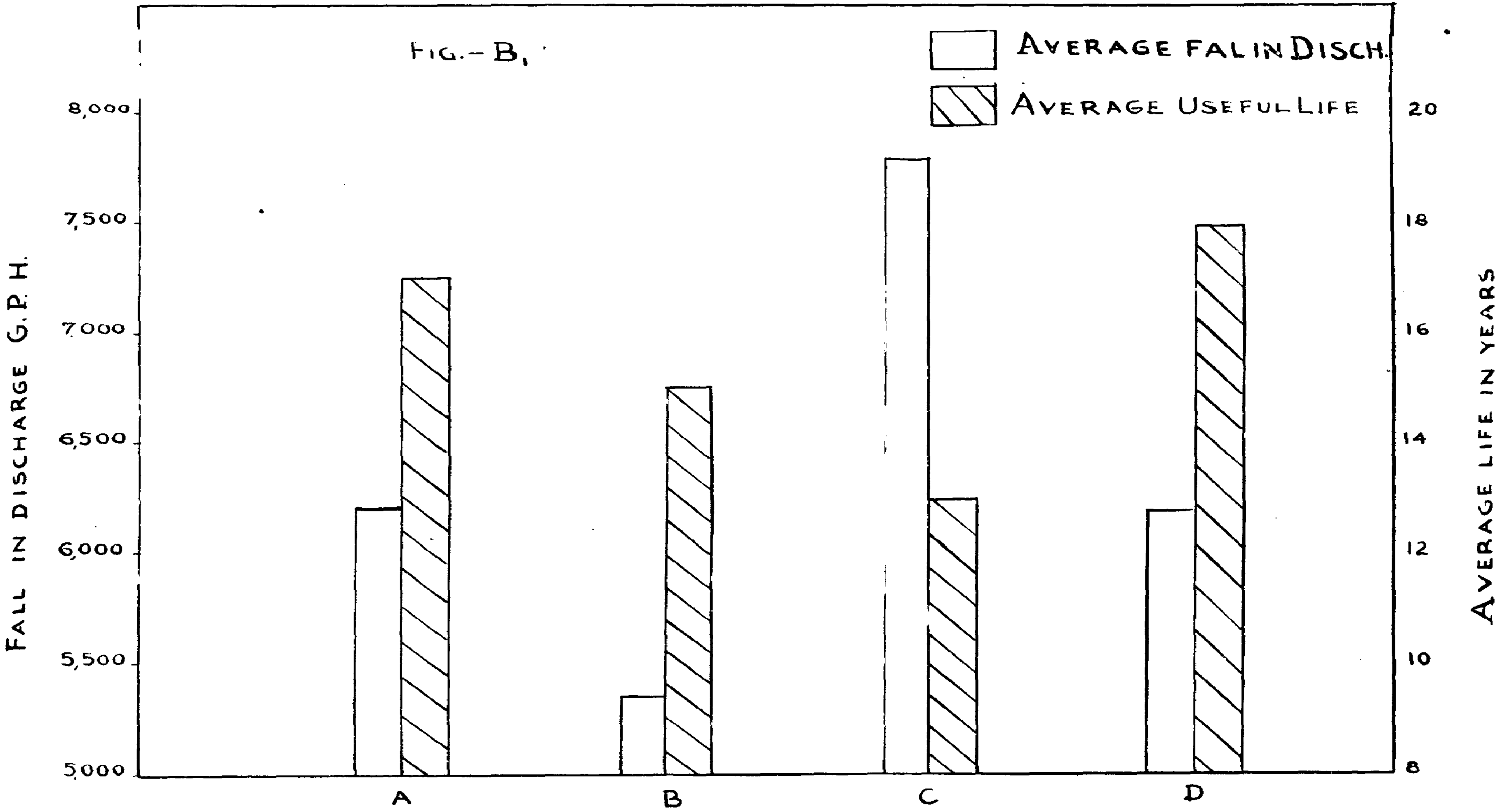
Name of District and Group.	Nos.of wells examined.		Useful life in years.		Average fall in discharge G.P.H.		Average yearly hours run.	
	Abondoned.	In service.	Abondoned.	In service	Abondoned.	In service.	Abondoned.	In service.
DIST.MEERUT:								
Lohara Group-	-	3	-	19	-	5,000	-	10,200
Daha Group.	-	3	-	28	-	7,400	-	15,600
DIST.MUZZAFARNAGAR:								
Muzzafarnagar Group.	-	8	-	36	-	19,800	-	11,100
Deoband Group.	-	6	-	16	-	12,100	-	8,200
DIST.SAHARANPUR:								
Saharanpur Group.	-	9	-	37	-	15,000	-	11,300
Nakur Grmoup.	-	5	-	21	-	10,800	-	14,200
Roorkee Group.	-	19	-	147	-	75,600	-	36,700
Deoband Group.	-	10	-	70	-	23,600	-	27,500
DIST.ALIGARH:								
Aligarh Group.	2	5	16	28	8,900	7,800	6,000	11,600
Mathura Group.	-	1	-	5	-	2,900	-	2,000
Atrauli Group.	-	5	-	35	-	6,300	-	8,400
Total of wells examined:	2	74	16	442	8,900	1,85,300	6,000	1,56,900
Average per well:	1	1	8	6	4,400	2,500	3,000	2,100

TABLE SHOWING FALL IN YIELD DURING VARIOUS PERIODS.

S L O T T E D - W E L L S.

Name of District and Group.	Wells-servine 0-4 years.			Wells-service from 0-8 years.			Wells-service 0-12 years.			Wells-service 0-16 years.		
	Useful life.	Average fall in discharge G.P.H.	Average yearly hrs.run.	Useful Average life.	Average fall in discharge.	Average yearly hours run.	Useful average life.	Average fall in discharge.	Average yearly Hrs. run.	Useful Ave. life.	Average fall in discharge.	Average yearly hours run.
DIST.MEERUT:												
Lohara Group.	-	-	B	5	2,000	2,600	9	1,000	5000	-	-	-
Daha Group.	-	-	-	5	1,700	4,200	9	800	5600	14	4,900	5800
DIST.MUZZAFARNAGAR.												
Muzzafarnagar Group.	4	2,400	1,200	8	2,900	2,900	-	-	-	-	-	-
Deoband Group.	3	2,000	1,400	-	-	-	-	-	-	-	-	-
DIST.SAHARANPUR:												
Saharanpur Group.	3	1,400	1,200	6	2,300	1,300	-	-	-	-	-	-
Nakur Group.	3	2,700	2,800	7	-	2,900	-	-	-	-	-	-
Roorkee Group.	3	5,600	1,900	8	3,100	1,900	9	5,100	2000	-	-	-
Deoband Group.	-	-	-	7	2,400	2,700	-	-	-	-	-	-
DIST.ALIGARH:												
Aligarh Group.	3	-	1,700	7	3,300	2,800	-	-	-	-	-	-
Mathura Group.	-	-	-	5	2,900	2,000	-	-	-	-	-	-
Atrauli Group.	-	-	-	7	300	1,500	10	2,600	2000	-	-	-
TOTAL:-	19	14,100	10,200	65	20,900	24,800	37	9,500	14600	14	4900	5800
Average per well:	3	2,300	1,700	6	2,100	2,500	9	2,600	3600	14	4900	5800

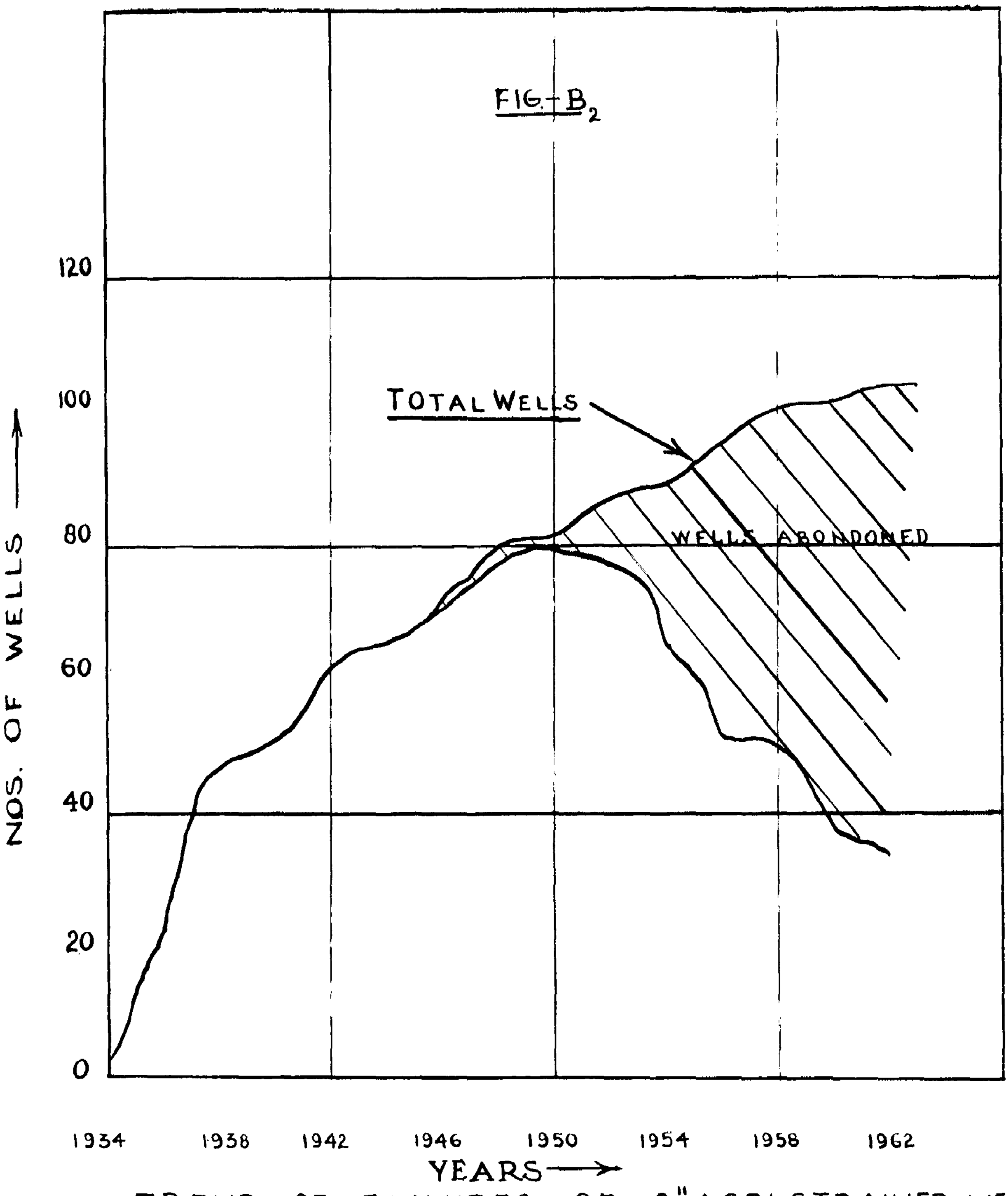
Fig.-B1



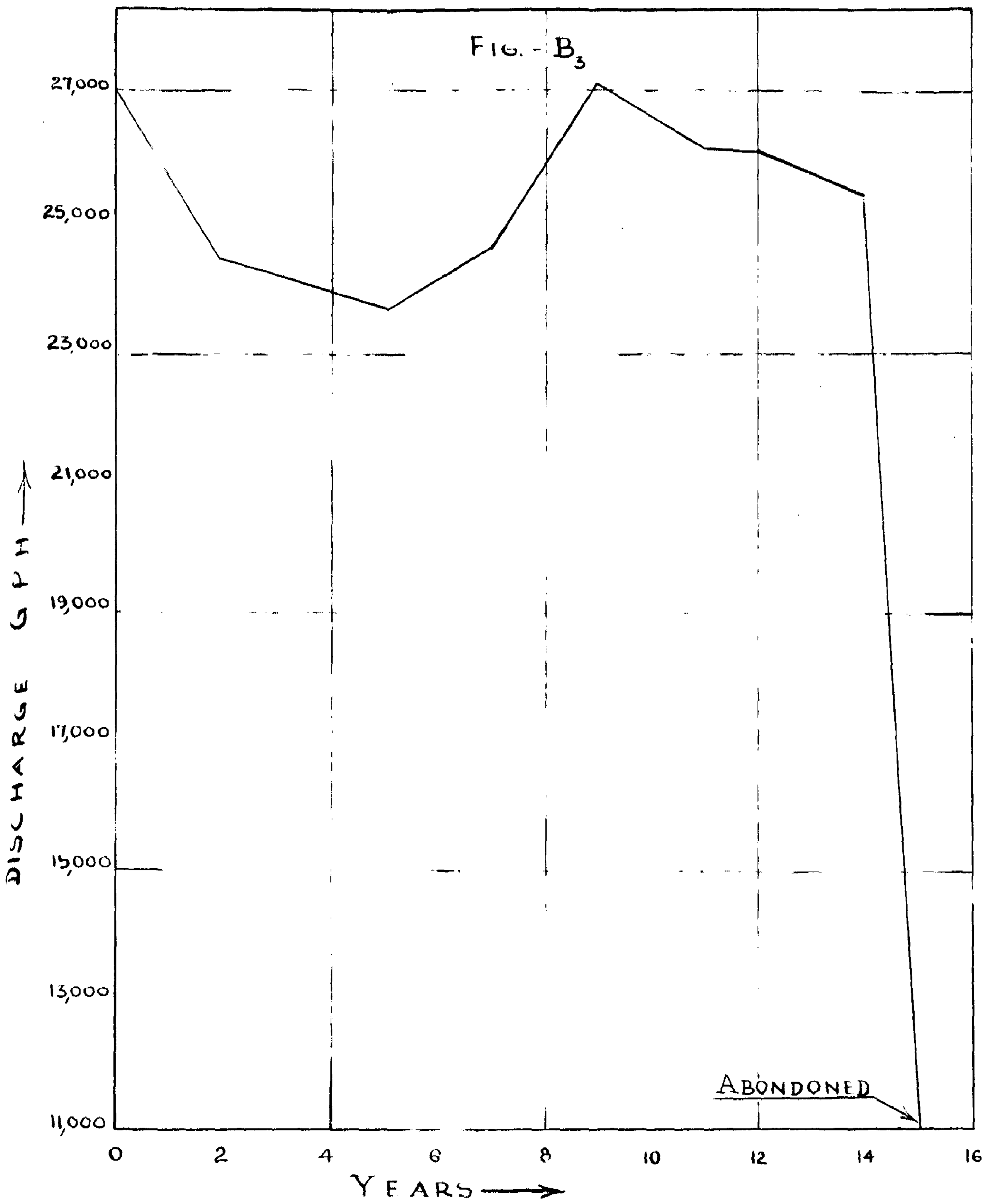
AVERAGE FALL IN DISCHARGE AND USEFUL LIFE OF WELLS

KEY LETTERS:

A = District Meerut
B = District MuzzafarNagar
C = District Saharanpur
D = District Aligarh

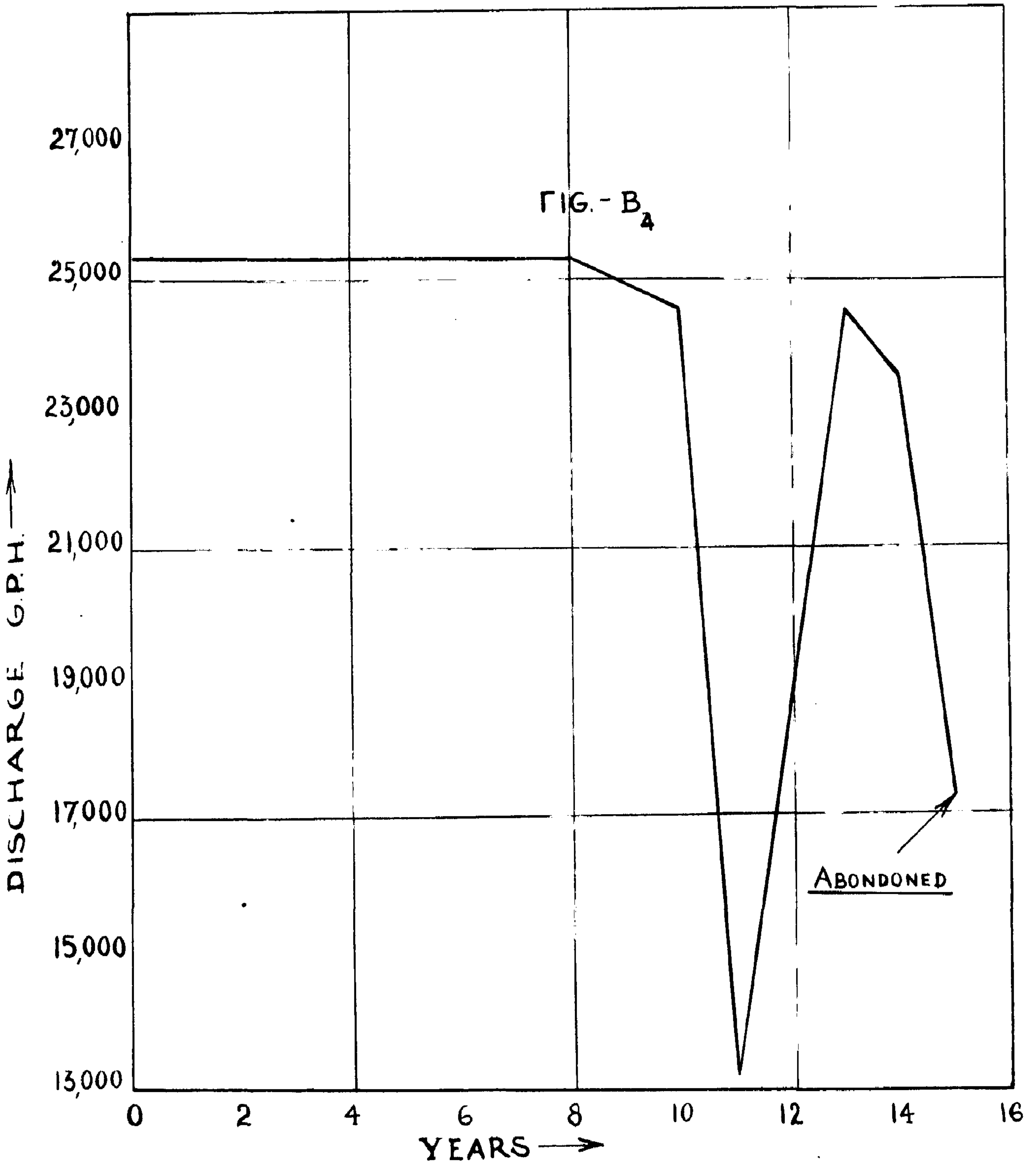


TREND OF FAILURES OF 6" AGRI STRAINER WELLS



REPRESENTATIVE FALL IN DISCHARGE OF T.W. NO. 1

SOUTH LOI GROUP - DIST MUZZAFAR NAGAR.



REPRESENTATIVE FALL IN DISCHARGE OF T. W. NO. 24 A
NORTH LOI GROUP DIST. MUZZAFAR NAGAR

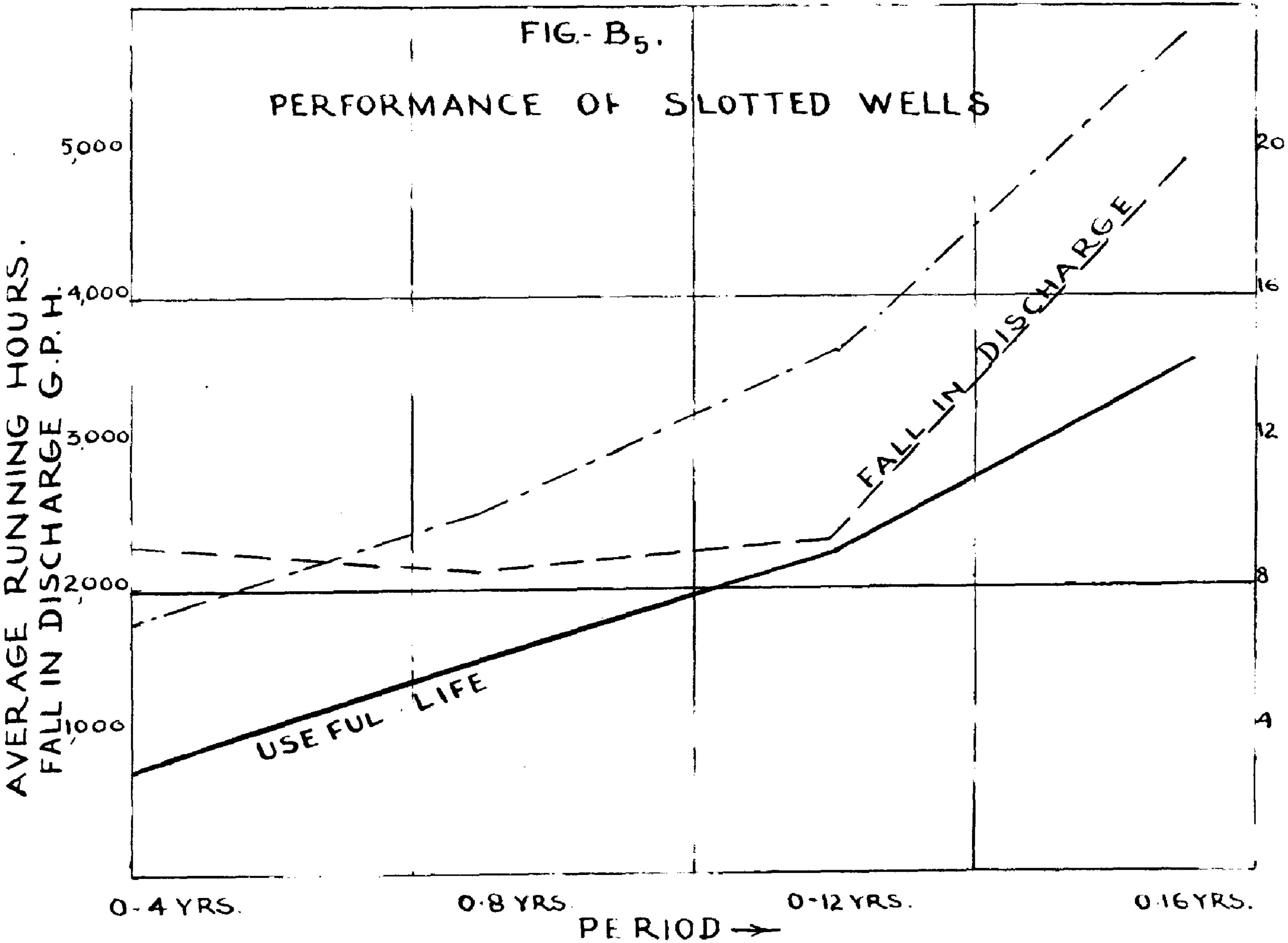


FIG.- B_5.

PERFORMANCE OF SLOTTED WELLS

DISTRICT - MEERUT:

TYPE OF WELL - 6" AGRICULTURAL STRAINER TYPE.

APPENDIX "B"

SURVEY OF TUBE-WELLS DATA

ABBREVIATIONS:
- C= Chocking of Strainer, Strata.
- S.D= Sand Discharge.
- S.R= Screen Rapture.
- A= Abondoned.
- R= Running.

Sl No.	Tube well No.	Year of Construction	Depth of boring / Length of Strainer	Year of observation of discharge	Discharge in G.P.H.	Useful life in years	Average fall in discharge in G.P.H.	Average running hours per year	Abondoned =A or running=R	Causes of failure or trouble	Remarks.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11	12.
MEERUT GROUP:											
1.	26	1943	278'-0" / 85'-5"	43	31161	13	7800	5000	A	S.D. + C + S.R.	Yield gradually decreased. In 1950, the well gave sand. 45' of 5" pipe was lowered in suction side which stopped sand for some time. Yield again decreased to 17,300 G.P.H. in '56. Sounding was 270' Chock-ing xxx 2701 and rupture of screen.
				46	28199						
				49	27251						
				50	24083						
				51	22796						
				55	20348						
				56	17300						
2.	21	1937	256'-0" / 99'-3"	37	36000	17	14,400	5000	A	S.D. + C + S.R.	Yield gradually reduced to 2379 g.p.h. in 50-51, and large quantity of sand was discharged. Lowering of 4" blind pipe stopped sand for some time. But huge quantity of sand again came in 52. Sounding was 225'-6". Chocking and rupture of screen.
				41	27251						
				49	25412						
				51	23796						
				52	15267						
				53	15267						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12
3.	27	1946	265'-0" / 99'-0"	46	35,388	10	9,700	3,800	A	S.D. + C	Yield gradually reduced and in 1954,thepump started hunting & giving sand,which increased much in 1955. Yield could not be increased. Sounding 256' Chocking of Strainer.
				50	32,708						
				52	29,167						
				54	23,649						
				55	21,961						
				56	21,100						
4.	23	1937	290'-0" / 93'-10"	37	28,500	15	7,000	5,000	A	S.D. + C + S.R.	Started giving sand in large quantity in 1950.Lowering of blind pipe in suction side stopped sand for some time but sand appeared again. Sounding was 180' in '51.Rupture of screen and chocking.
				41	24,083						
				44	24,522						
				49	23,649						
				51	188,07						
				52	16,631						
5.	52	1948	271'-0" / 99'-0"	48	35,388	15	1,900	3,500	R	S.D. + C.	Well started giving fine sand in 55 which still persists. Discharge has fallen gradually.Chocking of strainer.
				54	32,188						
				56	35,400						
				58	33,234						
				63	33,234						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
6.	20	1937	234'-0" / 93'-3"	40	22,700	23	4,400	2300	R	S.D	In 1955, the well started giving sand and the discharge gradually fell down. Sandstill continue. Discharge could not be improved upon. Chocking of strainer (Capacity of well taken as 27722 g.p.h.).
				43	27,722						
				48	27,722						
				51	25,412						
				54	21,900						
				58	21,900						
				60	19,956						
				63	18,800						
7.	20A	1944	281'-0" / 108'-0"	44	29,167	18	7,000	6,500	R	S.D.	Discharge gradually fell down. Thewell started discharging sand in 54. The yield has further gone down Major overhauling of pump could no increase the discharge.
				54	24,964						
				56	23,649						
				61	21,961						
				62	18,307						
				62	21,961						
8.	23R	1937	200'-0" / 103'-6"	53	35,388	10	2,500	2,700	R	C.	No trouble except the discharge has slightly gone down.
				56	31,161						
				60	33,765						
				62	34,301						
				63	32,188						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
9.	24	1937	300'-0" / 100'-0"	37	35,400	25	13,130	3,200	R	C	No trouble except the discharge has considerably gone down. Chocking of Strainer.
				43	26,322						
				53	27,251						
				57	22,376						
				60	18,064						
				63	17,338						
10.	28	1946	300'-0" / 99'-0"	46	35,388	17	11,200	4,100	R	S.D. + C	Discharge of the well has fallen down considerably. The well has started giving sandin small quantity since 1957, which still persists. Chocking of strainer.
				51	31,161						
				56	25,412						
				58	23,500						
				60	22,796						
				61	21,961						
				63	20,348						
11.	33	1946	285'-0" / 81'-0"	46	35,388	17	9,800	3,300	R	S.D. + C	Discharge of the well has gone down considerably.The well hasstarted discharging sand in small quantity since 1958.Chocking of Strainer.
				54	31,161						
				58	24,400						
				61	25,220						
				62	23,649						
				63	23,649						

1.	2.	3.	4.	6.	6.	7.	8.	9.	10.	11.	12.
12	35	1947	220'-0" / 99'-0"	47	38,771	16	7000	3,900	R	S.D. + C	The discharge is continuing to fall. Pipe 4" dia. 40' was lowered in suction side which stopped the sand The sand started coming in 1955 in large quantity. Chocking of strainer.
				51	37,037						
				54	33,765						
				55	31,161						
				59	33,234						
				61	28,199						
				63	27,251						
13.	43	1952	280'-0" / 99'-8"	52	36,445	10	3,900	2,300	R	C	No trouble except the discharging is falling. Chocking of strainer.
				56	33,200						
				58	33,200						
				62	31,161						
14.	46	1956	380'-0" / 107-8"	56	41,722	7	3,600	2,100	R	C	No trouble except the discharge has fallen slightly. Chocking of strainer.
				58	35,388						
				60	39,940						
				62	37,057						
				63	39,940						
15.	54	1958	-	58	41,129	8	3,900	1,600	R	C	No trouble except the discharge is decreading. Chocking of strainer.
				60	39,940						
				61	36,495						
				62	37,057						
				63	35,388						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
16.	59	1959	-	59	33,234	4	5,000	2,000	R	C	No trouble except the discharge is falling. Chocking of Strainer.
				60	27,251						
				61	29,167						
				62	28,199						
17.	53	1958	-	58	46,097	5	4,000	-	R	C	---------do----------
				60	43,571						
				61	44,882						
				62	39,940						
				63	39,940						
18.	57	1959	-	59	42,340	4	2,700	-	R	C	---------do-----------
				60	39,940						
				61	42,340						
				62	36,495						
				63	39,940						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
LOHARA GROUP:											
19.	3A	1936	309'-0" / 100'-0"	36	24,452	19	2,700	5300	A	S.D. + S.R.	Starting giving sand in large quantity in 1942 Blind pipe 4" dia 36' was lowered in the suction side which reduced the sand discharge. In 54, the sounding was 274' and sand discharge was heavy and continuous. Screen rupture.
				40	20,300						
				42	22,722						
				48	26,200						
				51	21,961						
				54	23,649						
				55	15,940						
20.	7	1936	341'-0" / 92'-3"	36	27,252	17	5,900	6,300	A	S.D. + C	The discharge decreased considerably. Higher pumping sets were installed in 45 and 52 to get more discharge. But it again reduced. Well started giving sand and sets were quickly work out. Chocking of strainer.
				44	25,412						
				45	29,267						
				50	18,064						
				51	12,7[illegible]						
				52	25,412						
				53	17,338						
21.	5A	1941	290'-0" / 88'-4"	41	28,199	13	3,300	6,500	A	C	Well started giving sand in large quantity in 1950 Pipe 4" was lowered in the suction side which reduced the sand discharge. In 53 hunting of pump started. Chocking of Strainer.
				45	27,251						
				50	27,251						
				51	23,649						
				54	21,551						

1.	2.	3.	4.	5.	6.	7.	8.Y	9.	10.	11.	12.
22.	2A	1942	300'-0" / 99'-0"	42	21,988	12	2,700	5,000	A	S.D. + C	Sand discharge started in 1950 which increased in 51. 35' of 4" pipe was lowered in suction side which decreased the discharge of sand. In 53,higher capacity pump was installed which increased the yield and sand discharge.Running became uneconomical.Chocking of strainer.
				47	22,796						
				51	12,158						
				53	21,146						
				54	21,146						
23.	11A	1937	350'-0" / 100'-0"	39	18,000	15	1,600	6,000	A	S.D. + C	In 52, the well started giving sand in huge quantity which persisted. Well was abundoned due uneconomical running. Chocking of Strainer.
				44	18,064						
				47	18,433						
				52	12,747						
24.	22	1949	-	49	25,412	13	3,500	3,600	R	C	No trouble except the discharge is falling down.
				54	25,412						
				57	24,522						
				59	20,348						
				60	20,348						
				62	18,807						
25.	32	1957	-	57	41,129	5	600	2,600	R	C	No trouble except the discharge isfalling.
				59	41,129						
				60	41,129						
				61	39,940						
				62	39,940						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
26.	40	1957	-	57	35,388	5	2,900	2,600	R	C	No trouble except tho discharge is falling.
				58	33,234						
				60	32,188						
				62	32,188						
27.	4	1937	282'-0" / 91'-10"	37	27,200	15	1,300	8,500	A	S.D. + S.R.	Sand discharge from the well bocamo excossive in 1952, . [illegible] In 1952 a reconditionod pump was installed which incroa-sed the yield to 27000 g.p.h. But there was heavy sand [illegible] and clay-discharge. Rupture of scroon.
				39	27,200				10		
				41	27,200						
				43	26,412						
				45	27,251						
				47	28,199						
				49	28,380						
				51	28,199						
				52	19,186						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
DAHA GROUP:											
28.	20	1936	320'-0" / 81'-4"	36	27,252	23	2,700	5,700	A	S.D. + C + S.R.	Sand discharge started in appreciable quantity in 57, which increased very much by 59. Sounding was 123' and and ultimately the same year yield fell down to 10,000. Sounding was 126'.Screen ruptured.(Yield of 59not taken into account for column 8).
				55	24,522						
				56	23,649						
				58	25,412						
				59	24,500						
				59	10,000						
29.	1	1937	297'-0" / 85'-0"	37	26,340	19	6,500	5,600	A	C	The discharge starting falling gradually from 52. The well gave a discharge 18,000 with Sluice valve throllted to ⅓rd Hunting was there.Chocking of strainers.
				52	21,146						
				55	20,348						
				56	18,000						
30.	28	1936	331'-0" / 85'-0"	36	27,252	15	4,200	5,700	A	S.D. + S.R.	The well wasdischarging sand in small quantity since gegining.It became excessive in 42. in 1945 pump had to be changed. The discharge continued to fall.It became 12,158 in 1/51 with heavy sand discharge.Rupture of screen.(Yield of 51 not taken into account for column 8).
				42	24,964						
				44	26,322						
				46	25,412						
				48	21,146						
				49	17,338						
				51	12,158						
31.	3	1936	299'-0" / 84'-0"	36	27,252	21	6,100	5,800	A	S.D.	Well started giving sand in 48 which increased very much in 54.In 55,the bore was felled withsand and clay.Replugging of 6" and 12" joint was done
				40	22,000						
				44	22,796						

1	2	3	4	5	6	7	8	9	10	11	12
31				53	20,348						which reduced the sand considerably. But heavy sand discharge again appeared. Screen deputed.
				55	21,196						
				56	20,348						
				57	20,348						
32	5	1936	300'-0" / 119'-2"	36	27,252	10	4,400	8,000	A	S.D. + S.R.	Discharge fell down upto 3/40. A higher pump was then installed. Sand started in 42 sounding in 43 was 283'. Rupture of bottom portion of screen as the sand continued and the bore could not be sludged.
				38	25,384						
				40	29,200						
				42	24,083						
				44	18,064						
				46	17,522						
33	26	1941	286'-0" / 100'-0"	41	29,167	11	4,100	6,000	A	S.D. + C	From 48, the well started giving sand in large quantity. Heavy repairs were done the 49 and 51 which increased the discharge temporarily. But the discharge continued to fall and due to persistent sand discharge, running of well was un-economical Chocking of strainer.
				43	28,599						
				47	23,649						
				48	26,200						
				49	25,412						
				51	23,649						
				52	22,706						
34	22	1938	333'-0" / 98'-10"	38	21,180	16	1,300	6,400	A	C + S.[illegible].	The discharge fell down

1	2	3	4	5	6	7	8	9	10	11	12
				40	19600						considerably in 47, a higher capacity pump was installed which increased the discharge but the sand appeared. Bore fitting upto 18' was found which could not be sludged. In 53, pump was again replaced which increased the discharge but hunting appeared.
				41	16,982						
				42	18,064						
				47	23,649						
				52	18,807						
				53	21,146						
				54	21,146						

1	2	3	4	5	6	7	8	9	10	11	12
SARDHANA GROUP											
35	23	1946	323'-0" / 101'-5"	46	28,681	24	5,600	4,400	A	S.D. + C + S.R.	Discharge gradually reduced. In 1954, sand discharge increased. In 54 , entire pump set was reconditioned. Lower most strainer ruptured. And other portion chocked.
				48	27,722						
				52	25,412						
				54	21,961						
				55	25,412						
				56	23,649						
				58	20,348						
				60	14,612						
36	3	1935	249'-6" / 92'-10"	35	31,100	25	9,400	5,100	A	S.D. + C	Discharge gradually reduced. [illegible] and frequent repairs of pumping set were done to increase discharge . Maintenance became very costly. Chocking of strainer.
				40	24,000						
				46	21,146						
				50	23,649						
				52	19,186						
				55	24,522						
				58	21,961						
				59	21,961						
				60	17,338						
37	1	1937	256'-0" / 89'-3"	37	26,300	17	8,400	4,600	A	C	Discharge has gone down considerably and the running of well became un-economical. Strainer Chocking.
				41	22,796						
				43	21,551						
				47	20,348						
				49	17,338						

1	2	3	4	5	6	7	8	9	10	11	12
				51	15,267						
				53	14,612						
				54	13,351						
38	13	1936	264'-0" / 94'-0"	36	26,200	19	2,900	4,800	A	S.D. + S.R.	In 47' the well started giving sand which became excessive the 48, pump house sank and crach developed. 5"pipe was lowered in the suction side to stop sand. In 53, sounding revealed a 10' fitting of bore which could not be cleared which was later on plugged. The discharge went on decreasing and the running of well became uneconomical.
				39	22,700						
				42	26,322						
				47	25,412						
				51	26,326						
				53	20,348						
				54	21,146						
				55	21,146						
39	18	1937	351'-0" / 96'-0"	37	31,100	19	4,900	4,700	AS	S.D. + S.R.	Sand discharge startedin 45. In 1946 pipe 5" was lowered in the suction side which reduced the sand discharge. But it again increased. In 1952, the sounding revealed a bore fitting of 14' which could not be sludged. Screen rupture.
				39	29,100						
				41	27,251						
				42	26,784						
				45	27,251						
				48	25,412						

1	2	3	4	5	6	7	8	9	10	11	12
				54	25,412						
				55	24,522						
				56	23,649						
40	15	1937	317'-6" / 92'-10"	37	30,700	23	3,500	4,000	A	C	The discharge of the well gone down considerably chocking of strainer.
				38	31,100						
				42	30,655						
				45	29,167						
				49	28,199						
				52	26,326						
				54	25,412						
				58	22,796						
				59	23,649						
				61	17,338						
41	2	1937	250'-0 / 98'-8"	37	27,250	21	3,700	5,000	A 24	S.D. + C	The well started giving sand lately and the yield also reduced considerabely. Uneconomical running. Chocking of Strainer.
				41	21,146						
				43	21,146						
				45	20,348						
				47	22,796						
				50	21,146						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
				52	24,964						
				56	21,961						
				58	18,807						
42	29	1959	302'-0" / 129'-0"	59	39,940	4	4,000	3,100	R	C	The yield from the well has gone down slightly. Chocking of strainer.
				60	37,623						
				61	35,388						
				62	35,388						
				63	35,388						

1	2	3	4	5	6	7	8	9	10	11	12
	BHATIPURA GROUP.										
43	T.I.H.	1942	300'-0" / 99'-0"	42	32188	12	7,200	5,100	A	S.D. + S.R. + C	After 43, the yield began to fall and the well also started giving sand. In 49, pipe 4" was lowered in the suction side which stopped sand for alarta year. But the sand again appeared and by 54, the yield reduced considerably. Sounding was 265'. Screen rupture and chocking of screen.
				44	31,161						
				46	32,188						
				49	29,157						
				51	23,649						
				52	17,338						
				54	16,631						
44	T.I. D.	1935	291'-6" / 80'-5"	35	40,000	19	13,600	4,600	A	S.D. + C	Yield from the well soon fell down to 26,784 in 43. and well also started giving sand. Installation of high capacity pump in 49 increased the yield to 32,188 but it again quickly fell down. Sand quantity increased. Lowering of pipe in suction sid could not stop stop sand. Sounding was243'. Back washing by plunger method did not increase the yield cocking of screen.
				36	38,850						
				41	29,167						
				43	26,784						
				49	32,188						
				51	27,251						
				52	20,348						
				53	18,807						
				54	17,699						

1	2	3	4	5	6	7	8	9	10	11	12
BHATIPURA SOUTH GROUP											
45	45	1937	290'-0" / 87'-0"	37	31,400	23	8,900	4,100	A	S.D. + C	After 49' the well started giving sand. Pipe 4" was lowered in the suction side in 1951 which stopped the sand for some time but with reduced discharge. Which went on decreasing further. The sand discharge became excessive in 1959. Chocking of strainer.
				39	29,100						
				42	27,722						
				45	24,083						
				51	21,146						
				55	19,186						
				58	19,569						
				59	20,348						
				60	18,807						
46	44	1935	224'-0" / 94'-7"	35	31,700	25	6,700	3,400	A	S.D. + S.R.	The yield from the well gradually reduced. In 51, the well started giving excessive quantity of sand which continued. In 60, sounding was 130'. Rupture of strainer.
				37	31,300						
				40	27,200						
				51	23,649						
				55	22,796						
				59	24,522						
				60	20,348						

1	2	3	4	5	6	7	8	9	10	11	12
47	51	1942	300'-0" / 99'-0"	42	29,167	14	7,200	4,000	A	S.D. + C	Well started giving sand in 1951. Overhauling of set did not improve the discharge. Sand discharged continued and in 1954, the ground started sinking due to formation of cavity. Due to uneconomical running the well was abondoned. Screen chocking.
				46	29,167						
				48	27,251						
				51	25,251						
				54	22,796						
				55	14,612						
				56	12,195						

1	2	3	4	5	6	7	8	9	10	11	12
DAURALA DISTRIBUTORY											
48	C-4	1935	256'-0" / 119'-3"	35	43,800	21	13,100	3,800	A	S.D. + C	Yield reduced considerably by 40141. Efforts were made to improve the discharge but in the no result. In 44, the well started giving excessive sand. Pipe 6" was lowered in the suction side to stop sand. But the discharge wen on reducing and it became un-economical chocking of strainer.
				40	35,400						
				51	33,234						
				54	27,251						
				55	29,167						
				56	28,199						
49	C-1	1935	281'-6" / 128'-3"	35	51,500	21	9,300	3,800	A	S.D. + C	Yield came down to 34301 p.h. in 41. Different methods were employed to improve the discharge and it becomes 41,844 g.p.h. in 47. In 1948, the well started giving sand in excessive quantity and the discharge again fell down. It was abondon due to un-economical running. Chocking of strainer.
				42	34,301						
				47	41,844						
				56	21,251						

1	2	3	4	5	6	7	8	9	10	11	12
BHTIPURA NORTH-GROUP.											
50	3	1934	178'-0" / 100'-8"	34	28,200	21	7,100	4,000	A	S.D. + C	Yield from the well reduced rapidly. Pump repairs in 44, increased the yield to 23,640 g.p.h.with increased depression.From 49 onwards, sand started coming. Sounding was 170'. Chocking of strainer.
				37	26,280						
				39	20,280						
				41	25,412						
				44	21,961						
				47	24,083						
				49	21,146						
				51	19,569						
				55	10,000						

1	2	3	4	5	6	7	8	9	10	11	12
GHAZIABAD GROUP											
51	15	1937	$\frac{275'-0''}{72'-0''}$	37	29200	14	8500	6000	A	S.D. + S.R.	From 4/51, the well started giving huge quantity of sand and yield reduced to 12,000 g.p.h. Sounding was 120'. Box could not be sludged. Screen was ruptured. Ruptured portion was plugged but the yield obtained was 4000 g.p.h.
				38	28807						
				39	18840						
				42	17338						
				43	18064						
				51	20348						
52	12	1937	-	37	21900	19	4900	6400	A	S.D. + C	The well started giving sand lately. which went on increasing. In 44, there was no yield except heavy amount of sand and clay. Lowering of blind pipe in suction side stopped sand for some time the discharge again reduced gradually chocking of strainer.
				44	18807						
				56	15267						

SOUTH LOI GROUP

1	2	3	4	5	6	7	8	9	10	11	12
55	1	1938	311'-0" / 108'-2"	38	27240	15	3600	5,200	A	S.D. + S.R.	The sand discharge went on increasing gradually and frequent repairs were done. In 1/53, the sand discharge because excessive suddenly and yield reduced to 11032 Rupture of screen.
				40	24500						
				43	23649						
				45	24822						
				47	27251						
				49	26200						
				50	26200						
				52	25412						
				53	11032						
54	1R	1953	317'-0"	53	32188	8	9500	4,600	A	S.D. + S.R.	Sand discharge began in 58. In 60, the yield became 10,000 g.p.h. The overhauled pump was fitted which increased the discharge to 23,649 g.p.h. But within 3 months it dropped down to 6343 g.p.h. Sounding was 256'. No success in sludging Heavy sand persisted screen rupture.
				54	32188						
				55	32188						
				56	31140						
				57	25412						
				58	17338						
				59	23649						
				60	10000						
				61	9436						

1	2	3	4	5	6	7	8	9	10	11	12
55	3	1937	308'-2" / 120'-2"	37	27240	14	4800	7300	A	S.D. + C	The well started giving sand in 1949 which became excessive in 53. The bore used to fill with sand and it was not possible to get more and sand clear yield. Chocking.
				44	25300						
				45	28199						
				47	26200						
				48	22796						
				49	21146						
				50	14612						
				52	25912						
				53	20348						
				54	17338						
56	9R	~~1964~~	~~304'-6"~~	~~37~~	~~27240~~						
56	9R	1961	318'-0" / 91'-2"	61	27251	2	4400	4900	R	S.D. + C	The well is giving sand in smal quantity and the yield has been reduced to obtain a sand free discharge. Chocking of strainer
				62	25412						
				63	20348						

1	2	3	4	5	6	7	8	9	10	11	12
57	7	1937	304'-6" / 98'-4"	37	27240	26	7500	5600	R	S.D. + C	Sand discharge went on increasing as the time rolled on and is very excessive now. Frequent heavy repairs are required. Chocking of strainer.
				56	25412						
				57	21960						
				58	9970						
				59	27251						
				60	10000						
				61	23649						
				62	25412						
				63	14612						
58	14	1937	322'-0" / 94'-0"	37	25300	17	6700	6200	A	S.D. + S.R.	There was minute sand discharge in the beginning which went on increasin as the time and became excessive in 52 which could not be checked. Screen rupture.
				39	19500						
				41	15940						
				43	20348						
				45	18807						
				47	18064						
				49	17338						
				50	14612						
				52	23649						
				54	18807						

1	2	3	4	5	6	7	8	9	10	11	12
59	16R	1957	302-0" / 98'-4"	57	33234	6	6200	4700	R	S.D. + C	The well is giving sand and the discharge is falling. Chocking.
				58	33234						
				59	29167						
				60	28199						
				61	23649						
				62	23649						
				63	24496						
60	14R	1955	323'-0" / 90'-8"	55	26237	8	1300	5500	R	S.D. + R	Sand discharge in small quantity yield has fallen down, frequent pump repairs are required. Chocking.
				57	25412						
				59	28199						
				61	27251						
				62	23649						
				63	20348						

1	2	3	4	5	6	7	8	9	10	11	12
NORTH LOI GROUP.											
61	18	1937	375'-0" / 100'-0"	37	29,100	22	6,900	4,800	A	S.D. + S.R.	Sand discharge from the well gradually increased and became excessive in 1959. Pipe 4" dia was lowered in the suction side but sand could not be diminished. Screen rupture.
				49	23,649						
				51	22,796						
				53	17,338						
				55	22,796						
				57	25,412						
				59	21,146						
62	24A	1945	-	45	25,412	15	3,400	4,700	A	S.D. + S.R.	Sand discharge from the well gradually increased. In 1960, there was heavy sand discharge with almost nil yield. The bore was found completely filled with sand which could not be cleared. Screen rupture.
				51	25,412						
				53	25,412						
				55	24,522						
				56	13,351						
				58	24,522						
				59	23,649						
				60	17,338						
63	36	1937	275'-0" / 100'-0"	37	23,400	20	6,400	4,900	A	S.D. + C	There was continually sand discharge with fall in yield Abondoned due to low yield.

1	2	3	4	5	6	7	8	9	10	11	12
				47	23,649						Chocking of strainor.
				50	24,522						
				52	14,612						
				54	13,660						
				55	12,747						
				56	15,267						
				57	14,612						
64	37	1937	270'-0" / 100'-0"	37	27,000	26	7,200	5,000	R	S.D. + C	Sand dischargo from tho woll gradually incroased and becauso oxcessivo in 53. Pipo 4" dia was n lowored in tho suction sido which reduced tho sand. But it has again increased. Chocking of strainor.
				53	23,649						
				54	20,744						
				56	21,961						
				58	18,807						
				60	17,338						
				62	18,807						
				63	17,338						
65	37A	1947	300"-0' / 105'-1"	47	33,234	16	9,300	5,600	R	S.D. + C	Tho woll is giving largo quantity of sand continious. Pumping sots worn out quickly. Chocking of strainor.
				54	28,199						
				56	28,681						
				58	25,412						
				60	20,348						
				62	18,807						
				63	21,961						

1	2	3	4	5	6	7	8	9	10	11	12.
KAIRANA GROUPT.											
66	1	1946	300'-0" / 27'-0"	54	23,649	9	3,000	5,500	R	S.D.	The well started giving sand in 1952. In harge quantity. Pipe 4" was lowered in the suction side which stopped the sand.
				55	20,744						
				56	24,522						
				58	20,348						
				60	17,338						
				62	19,807						
				63	21,961						
67	3	-	300'-0" / 103'-0"	54	21,146	9	2,700	5,000	R	-	The yield from the well is gradually falling. There is no other trouble on the well.
				56	20,348						
				58	21,161						
				60	18,064						
				62	16,631						
				63	15,940						

1	2	3	4	5	6	7	8	9	10	11	12
KAKRA GROUP											
68	4	1938	-	38	18,830	16	1,500	5,000	A	S.D. + C	Original discharge of the well was supplemented by another nearly boring and the yield increased to 28681 g.p.h. in 49. Lately the well started giving sand which went on increasing. Frequent repairs well required. Lowering 4" pipe was not helpful .Due to un-economicalx running the well had to be abondoned. Chocking of strainer (Original well capacity taken as 28199 g.p.h.)
				46	28,199						
				47	28,681						
				49	28,681						
				51	27,251						
				53	27,251						
				54	20,348						
69	13	1938	-	38	31,152	18	4,300	4,600	A	S.D. + C	Sand discharge from the well because very excessive in 53 which could not be reduced by any method. Pipe 4" was lowered in the suction side but with no effect. Maintenance became very costly. Chocking of strainer.
				47	28,199						
				49	31,161						
				51	31,161						
				53	23,649						
				54	24,512						
				55	23,649						
				56	25,412						

1	2	3	4	5	6	7	8	9	10	11	12
70	21	1948	320'-0" / 101'-2"	48	31,161	14	5,800	4,900	R	S.D. + C	The well discharges sand in small quantity. And the yield is constantly falling. Chocking of strainer.
				54	29,167						
				55	25,412						
				58	27,251						
				60	27,251						
				61	24,522						
				62	18,807						

1	2	3	4	5	6	7	8	9	10	11	12
		JANSATH GROUP.									
71	3	1942	395'-0" / 100'-0"	42	31,161	16	3,600	5,100	A	S.D. + S.R.	The well started giving sand in 53 which became too much in 58 and it was not possible to operate it further. Rupture of screen.
				44	29,167						
				45	31,161						
				47	29,167						
				51	31,161						
				53	29,167						
				54	26,784						
				56	23,649						
				58	20,348						
72	6	1948	-	48	30,154	15	7300	3,500	R	S.D. + C	The well started giving sand in 54 which became excessive. Yield has gone down. Frequent repairs Chocking of strainer.
				52	33,765						
				53	29,167						
				55	24,522						
				57	20,348						
				59	17,338						
				61	18,807						
				62	20,348						
				63	18,807						

1	2	3	4	5	6	7	8	9	10	11	12
73	7	1948	-	48	36,495	15	15,900	1,900	R	S.D. + C	The well discharging sand and yiel has gone done considerably since 1957. Chocking.
				54	32,234						
				55	28,199						
				57	23,649						
				59	20,348						
				60	17,338						
				61	15,940						
				62	15,267						
				63	12,158						
74	7A	1948	-	48	31,161	7	7,100	4,400	A	S.D. + R.	Sand discharge from the well gradually increased In 58 there was heavy nesh of sand which could not be stopped. Rupture of screen.
				50	33,234						
				52	25,412						
				53	23,649						
				54	22,796						
				55	15,267						

1	2	3	4	5	6	7	8	9	10	11	12
75	10	1947	280'-0" / 100'-0"	47	35,388	11	5,500	4,000	A	S.D. + R	Sand discharge from the well gradually increased. In 58 there was heavy nesh of sand which could not stopped. Rupture screen.
				49	35,388						
				50	37,623						
				53	35,388						
				[illegible]	33,234						
				56	25,412						
				57	20,348						
				58	21,961						
76	13	1952	-	52	31,161	7	7,100	2,300	R	S.D. + C	The well is discharging sand and the yield from the well is falling. Chocking of strainer.
				53	31,161						
				54	30,154						
				55	25,412						
				56	25,412						
				57	18,064						
				58	20,348						
				59	18,064						

DISTRICT-SAHARANPUR

6" AGRICULTURAL STRAINER TUBE-WELL.

1	2	3	4	5	6	7	8	9	10	11	12
	SAHARANPUR GROUP.										
77	1	1942	6 - / 91'-9"	42	19,584	13	2,000	2,600	A	C	Discharge from the well reduced considerably and it became un-economical to operate chocking.
				44	20,744						
				46	18,433						
				48	18,064						
				50	19,569						
				51	19,569						
				52	15,940						
				54	16,631						
				55	11,918						
78	2	1942	-	42	29,167	33	12,800	2,400	A	C	-do-
				44	27,251						
				46	22,796						
				48	21,961						
				50	16,283						
				52	11,587						
				54	7,195						
				55	7,380						

1	2	3	4	5	6	7	8	9	10	11	12
NAKUR GROUP.											
79	1	1942	-	42	31,161	16	7,400	4,400	A	C	Discharge from the well reduced considerably and it became un-economical to operate chocking.
				44	30,154						
				46	27,251						
				48	25,412						
				50	23,649						
				51	25,412						
				52	22,796						
				54	21,961						
				56	19,560						
				58	17,338						

1	2	3	4	5	6	7	8	9	10	11	12
ROORKEE GROUP.											
80	3	1951	[illegible]'-0" / 90'-6"	51	40,532	11	20,400	1,400	A	S.D. + C	Well was dischanging sand continiously. The bore is of length filled up with sand and yield is filling. Chocking of strainer.
				54	36,200						
				56	27,100						
				58	14,500						
				60	10,493						
				62	12,158						
81	4	1951	270'-0" / 99'-0"	51	20,348	11	(–) 3,900	2,200	A	S.D. + C	Sand discharge continous sludging of bore frequently required. Uneconomical running. Chocking of strainer.
				52	23,649						
				54	22,376						
				56	27,251						
				58	29,100						
				60	24,083						
				62	18,807						
82	5	1951	186'-0" / 91'-1"	51	35,388	11	7,900	3,700	R	S.D. + C	Yield is falling and the well is dischargin sand Chocking of Strainer.

1	2	3	4	5	6	7	8	9	10	11	12
				52	32,188						
				54	31,672						
				56	26,100						
				58	27,100						
				60	22,796						
				62	24,964						

DISTRICT - ALIGARH. 6" AGRICULTURAL STRAINER TUBE-WELSS.

1	2	3	4	5	6	7	8	9	10	11	12
ATRAULI GROUP.											
83	25	1938	234'-0" / 62'-0"	40	24,918	19	5,800	3,700	A	S.D. + C	In 1950, the well started giving sand . Pipe 4" was lowered in the suction side but with no result. The pump house was sinking. Due to un-economical running it was abodnned. Chocking of strainer.
				42	23,142						
				50	20,348						
				54	17,300						
				57	17,300						
				59	17,300						
84	24	1940	300'-0" / 62'-0"	40	16,631	15	-	3,800	A	S.D. + C	In 1941, the well started giving sand which gradually increased. The bore was back-washed and surged. Discharge increased. In,45 it was treated with chemicals which slightly increased the yield. In 47 it was again surged and washed and the yield increased to 23,500 g.p.h. But the sand became continous . In 55, yield was 15,900 g.p.h. Due to un-economical running it was abondoned. Chocking of strainer.
				41	15,267						
				43	20,345						
				45	19,196						
				47	20,900						
				50	23,500						
				53	23,500						
				55	15,900						

1	2	3	4	5	6	7	8	9	10	11	12
	KASGANJ GROUP.										
85	1	1941	300'-0" / 96'-0"	41	31,161	18	9,600	2,000	A	S.D. + C	In 45, the well started giving sand which gradually increased. Pipe 4" was lowered in the suction side which reduced sand but yield also reduced. Uneconomical running. Chocking of strainer.
				45	29,136						
				51	27,251						
				54	20,348						
				56	21,961						
				57	20,348						
				58	15,940						
				59	15,940						
86	9	1943	206'-0" / 70'-0"	43	21,961	17	5,400	3,300	A	S.D. + C	Sand discharge from the well gradually increased and yield fell down. Due to uneconomical running it was abondoned. Chocking of strainer.
				45	20,348						
				55	17,338						
				57	15,940						
				59	14,612						
				60	14,612						

1	2	3	4	5	6	7	8	9	10	11	12.
87	14	1941	334'-0" / 99'-0"	41	28,199	19	10,400	3,600	A	S.D. + S.R.	Sand discharge from the well gradually increased. In 1956, it was very excessive Sounding was 274' which could not be sludged. Rupture of screen.
				44	[illegible] 23,620						
				56	22,796						
				54	21,961						
				56	17,338						
				57	14,612						
				58	13,357						
				60	11,032						
88	11	1941	-	41	24,522	20	6,200	3,000	A	S.D. + S.R.	Sand discharge from the well increased. Air bubbles wese also coming. Top length pipe ruptured.
				45	21,961						
				50	22,796						
				54	21,961						
				59	17,338						
				60	14,612						
				61	11,032						

DISTRICT - MEERUT. 6" TEJ STRAINER TUBE - WELLS

1	2	3	4	5	6	7	8	9	10	11	12
BHATIPURA SOUTH GROUP.											
89	13	1934	- / 80'-0"	34	25,380	22 v	3,200	4,700	A	S.D. + C. + S.R.	From 1951, the well started giving sand. Pipe 4" of 40' length was lowered in the suction side which stopped sand. But discharge could not be improved uneconomical running.
				42	21,146						
				46	21,146						
				47	27,251						
				51	21,961						
				56	19,569						
90	3	1934	- / 80'-0"	34	28,680	22	8,700	4,800	A	C	Discharge went on falling despite frequent repairs. Chocking of strainer.
				41	22,796						
				42	24,522						
				55	15,267						
				56	17,338						
91	34	1935	- / 80'-0"	37	30,120	19	9,200	4,400	A	C	Discharge from the well gradually reduced despite frequent repairs. In 1956 the yield suddenly became 12159 which could not be
				47	24,083						
				54	21,961						

1	2	3	4	5	6	7	8	9	10	11	12
				55	25,412						improved upon-chocking of strainer.
				56	12,195						
92	36	1935	260'-0" / 80'-0"	35	37,672	25	10,300	3,200	A	S.D. + R.	In 1945, there was heavy sand discharged. Pipe was lowered in suction side. Again in 59 there was heavy sand discharge yield stopped in early 61. Sounding was 82'. Bore could not be sludged. Rupture of screen.
				36	33,200						
				38	33,200						
				39	29,100						
				44	28,681						
				46	19,569						
				60	20,340						

1	2	3	4	5	6	7	8	9	10	11	12
BHATIPURA NORTH GROUP.											
93	20	1937	245'-0" / 100'-0"	37	35,400	17	14,100	4,700	A	S.D. + C	There was graduall fall in well yield. From 1952, it started giving sand which increased and the yield further gone done. Abond-oned due to un-economical running. Chcoking of strainer.
				42	24,083						
				49	25,522						
				50	22,376						
				51	20,744						
				52	18,807						
				54	17,338						
94	15	1936	245'-0 / 80'-0"	36	22,320	15	4,700	5,100	A	S.D. + C	Since 47, there was conti-nious sand dischafge. Pipe 4" was lowered in the suc-tion side which reduced sand for some period. But it again increased and the xm yield of the well went on decreasing. Chocking of strainer.
				38	19,500						
				43	18,064						
				45	20,348						
				48	18,807						
				49	24,964						
				50	17,338						
				51	4,500						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
95	9	1936	195'-0" / 80'-0"	36	22,520	15	2,600	2,300	A	C	The well is running satisfactorily except the yield has reduced. Chocking of strainer.
				38	21,900						
				40	23,500						
				42	18,807						
				44	18,807						
				46	22,796						
				48	21,591						
				51	18,807						

1	2	3	4	5	6	7	8	9	10	11	12
			DAURALA DISTRIBUTORY.								
96	M-o	1935	380'-0" / 130'-0"	35	68,000	19	31,100	4,300	A	C	The yield from the well constantly reduced and did not serve the purpose for which it was made. Back washing and cleaning was done but with no effect. Chocking of strainer.
				41	65,656						
				44	37,623						
				46	35,400						
				49	30,154						
				51	29,167						
				53	33,234						
				54	27,251						
97	A-3	1935/7	288'-0" / 130'-0"	35	57,800	16	(-) 500	5,000	A	S.D. + S.R.	From 48, the well started giving sand. In 51, the well discharged Kankar and sand in large quatity. Sounding was 270'. One month later there was no discharge and sounding was 53'. The bore could not be sludged. Rupture of strainer.
				40	61,490						
				44	61,490						
				46	62,460						
				49	58,573						
				51	47,400						
98	E-4	1937	292'-0" / 100'-0"	37	500,48	22	10,000	4,500	A	S.D. + S.R.	In 1959, the well started dischargin course sand. Pipe 6" was lowered in the suction side which reduced

1	2	3	4	5	6	7	8	9	10	11	12
				46	44,849						sand. In 60, the well did not yield any water. Sounding was 63'. Bore could not be sludged. Rupture of screen.
				49	48,709						
				51	39,353						
				59	27,251						
				60	NIL.						

DISTRICT. MUZZAFAR NAGAR. **6" TEJ STRAINER TUBE - WELLS.**

1	2	3	4	5	6	7	8	9	10	11	12
DEOBAND GROUP.											
99	1	1956	$\frac{285'-0"}{100'-0"}$	56	35,388	6	2,300	2,300	R	C	The yield from the well has gone down slightly. Chocking of strainer.
				57	32,188						
				58	33,234						
				59	34,301						
				60	33,234						
				61	33,234						
				62	32,188						
100	3	1956	$\frac{340'-0"}{102'-0"}$	56	33,234	6	1,500	2,100	R	C	---do---
				57	33,234						
				58	32,188						
				59	34,301						
				60	31,161						
				61	32,188						
				62	27,281						
102	4	1955	$\frac{394'-0"}{108'-0"}$	55	32,188	7	800	1,900	R	C	---do---

1	2	3	4	5	6	8	9	10	11	12
PROBAND GROUP.										
				58	31,161					
				59	33,234					
				60	32,188					
				61	29,167					
				62	31,161					

DISTRICT - ALIGARH. 6" TEJ STRAINER TUBE-WELLS.

1	2	3	4	5	6	7	8	9	10	11	12
ATRAULI - GROUP.											
103	36	1937	220'-0" / 77'-0"	37	27,200	16	1,300	3,600	A	S.D. + R	From 1941, the wll started giving sand. Frequent repairs were required. In 54, the yiald from the well stopped. Sounding was 157'. Sludging could not be proceeded. Rupture øf strainer.
				39	25.380						
				41	22,796						
				42	29,167						
				47	27,251						
				50	27,251						
				53	23,500						

DISTRICT - MEERUT. **6" SLOTTED TUBE-WELLS.**

1	2	3	4	5	6	7	8	9	10	11	12
	LOHARA GROUP.										
104	23	1952	-	52	28,681	9	1,000	5,000	R	C	No trouble except the yield has fallen. Chocking of S. Tube and strata.
				53	30,154						
				55	28,199						
				56	27,722						
				58	29,167						
				59	29,167						
				60	25,412						
				61	23,649						
105	40	1957	-	57	35,388	5	3,400	2,600	R	C	---do---
				58	33,234						
				59	33,234						
				60	32,188						
				61	32,188						
				62	29,167						
106	41	1957	-	57	41,129	5	600	2,600	R	-	Well is running satisfactory.

1	2	3	4	5	6	7	8	9	10	11	12
				59	41,229						
				60	41,229						
				61	39,940						
				62	39,940						

1	2	3	4	5	6	7	8	9	10	11	12
	DARA GROUP.										
107	33	1957	343'-0" / 105'-8"	57	39,940	5	1,700	4,200	R	C	Yield from the well has slightly decreased. Chocking of S. tube and strata.
				59	39,940						
				60	38,194						
				61	38,194						
				62	36,495						
108	21	1953	345'-0" / 86'-0"	53	28,199	9	800	5,600	R	-	No trouble in the tube-well.
				55	27,722						
				56	29,167						
				58	29,167						
				60	22,796						
				62	28,199						
109	9A	1948	321'-0" / 218'-0"	48	34,301	14	4,200	5,800	R	S.D. + C	Yield from the well has gone down. Slight sand discharge. Chocking of S.tube and strata.
				53	28,199						
				54	28,199						
			5	56	27,251						

1	2	3	4	5	6	7	8	9	10	11	12
				58	32,188						
				60	29,167						
				62	31,161						

DISTRICT MUZZAFFARNAGAR. 6" SLOTTED TUBE WELLS.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
		MUZAFFARNAGAR GROUPE									
110.	12	1959	254'-6" / 102'-1"	59	35,388	4	1,100	1,600	R	-	There is no trouble in the well.
				60	34,300						
				61	34,300						
				62	34,300						
				63	34,300						
111.	13	1959	275'-10" / 99'-4"	59	33,234	4	800	200	R	-	-----do-------
				60	32,188						
				61	33,234						
				62	32,188						
				63	32,188						
112.	14	1959	247'-0" / 101'-1"	59	35,388	4	2,200	1,100	R	-	--------do--------
				60	33,239						
				61	33,234						
				62	33,234						
				63	33,234						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
113.	17	1959	254'-0" / 99'-8"	59	35,388	4	4,200	1,200	R	-	There is no trouble in the well.
				60	31,161						
				61	31,161						
				62	31,161						
				63	31,161						
114.	18	1959	233'-11" / 94'-5"	59	35,388	4	4,200	1,400	R	-	---------do-----------
				60	31,161						
				61	31,161						
				62	31,161						
				63	31,161						
115.	19	1959	276'-3" / 102'-11"	59	41,129	4	1,200	1,200	R	-	---------do-----------
				60	39,940						
				61	39,940						
				62	39,940						
				63	39,940						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
116.	22	1959	220'-5" / 102'-4"	59	36,495	4	3,200	1,500	R	C	The yield from the well is going down.
				60	35,388						
				61	35,388						
				62	31,161						
				63	31,161						
117.	5	1955	309'-10" / 100'-4"	55	31,161	8	2,900	2,900	R	S.D. + C	The well is discharging sand in minute quantity. yield has also gone down Chocking of slots and Strata.
				56	29,167						
				57	27,222						
				58	30,154						
				59	35,388						
				60	29,167						
				61	25,412						
				62	23,649						
				63	26,322						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
	DEOBAND GROUP:										
118.	29	1969	265'-2" / 180'-6"	59	39,940	4	[illegible]	1,500	R	-	There is no troublo in the well at present.
				60	42,340						
				61	42,340						
				62	37,623						
				63	37,673						
119.	30	1959	325'-0" / 104'-10"	59	36,495	4	3,800	2,000	R	S.D. + C	The well is discharging sand in minute quantity. Yield has also gone down Chocking of Slots and Strata.
				60	34,301						
				61	34,301						
				62	31,161						
				63	31,161						
120.	33	1959	275'-4" / 106'-6"	59	35,388	4	1,600	2,700	R	-	
				60	38,388						
				61	33,234						
				62	32,188						
				63	31,161						
121.	49	1962	297'-0" / 88'-11"	62	39,940	1	2,300	1,400	R	-	
				63	37,623						

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
122.	50	1962	380'-0" / 87'-3½"	62	37,623	1	2,200	4,00	R	-	
				63	35,388						
123.	65	1961	-	61	37,623	2	2,200	200	R	-	
				62	35,388						
				63	35,388						

****

DISTRICT - SAHARANPUR. 6" SLOTTED TUBE-WELLS.

1	2	3	4	5	6	7	8	9	10	11	12
	SHARANPUR GROUP.										
124	1	1956	450'-0" / 98'-2"	56	39,940	7	3,200	1,700	R	C.	Yield from the well is falling.
				57	39,940						
				58	37,623						
				59	37,623						
				60	37,623						
				61	31,623						
				62	37,623						
				63	35,388						
125	10	1959	-	59	39,940	3	7,700	1800	R	C	---do---
				60	35,388						
				61	33,254						
				62	29,167						
				63	31,161						
126	11	1958	-	58	31,161	5	2,400	900	R	C	----do----
				59	31,161						
				60	29,167						
				61	29,167						

1	2	3	4	5	6	7	8	9	10	11	12
	SAHARANPUR - GROUP.										
128	13	1960	-	60	36,495	3	1,100	1,800	R	S.D.	Discharging sand in small in the beginning.
				61	35,388						
				62	35,388						
				63	35,388						
129	14	1959	-	59	31,161	4	(-) 1,800	1,600	R	S.D.	Well is discharging sand but the discharge on the other hand has slighlly improved.
				60	34,301						
				61	33,234						
				62	31,161						
				63	33,234						
130	18	1959	-	59	37,633	4	2,800	1,600	R	S.D.	The well is discharging sand in the beginning. Yield of the well has also decreased.
				60	34,301						
				61	34,301						
				62	35,388						
				63	35,388						
131	15	1960	-	60	27,251	3	500	300	R	S.D.	There is no trouble in the well at present

1	2	3	4	5	6	7	8	9	10	11	12
				62	27,251						
				63	27,251						
127	9	1950	-	58	39,940	5	1,200	1,300	R	S.D.	Discharging sand in the beginning and the yield of well has slightly decreased.
				59	37,623						
				60	41,129						
				61	37,623						
				62	39,940						
				63	37,633						

1	2	3	4	5	6	7	8	9	10	11	12
SAHARANPUR - GROUP.											
128	13	1960	-	60	36,495	3	1,100	1,800	R	S.D.	Discharging sand in small in the beginning.
				61	35,388						
				62	35,388						
				63	35,388						
129	14	1959	-	59	31,161	4	(-) 1,800	1,600	R	S.D.	Well is discharging sand but the discharge on the other hand has slighlly improved.
				60	34,301						
				61	33,234						
				62	31,161						
				63	33,234						
130	18	1959	-	59	37,633	4	2,800	1,600	R	S.D.	The well is discharging sand in the beginning. Yield of the well has also decreased.
				60	34,301						
				61	34,301						
				62	35,388						
				63	35,388						
131	15	1960	-	60	27,251	3	500	300	R	S.D.	There is no trouble in the well at present

1	2	3	4	5	6	7	8	9	10	11	12
				61	27,251						except slight discharge of sand for a short time.
				62	25,864						
				63	27,251						
182	16	1960	-	60	18,807	3	(-) 2,100	300	R	S.D.	----do----
				61	21,961						
				62	20,348						
				63	20,348						

1	2	3	4	5	6	7	8	9	10	11	12
	N A K U R GROUP.										
133	YR-1	1956	-	56	39,940	7	-	2,900	R	S.D.	Heavy sand discharge from the well. Gravel is being fed.
				57	39,940						
				58	39,940						
				59	39,940						
				60	41,129						
				61	41,129						
				62	37,234						
				63	39,940						
134	IR	1961	-	61	30,154	2	(-) 1,000	7,000	R	S.D.	---do---
				62	31,161						
				63	31,161						

1	2	3	4	5	6	7	8	9	10	11	12
	ROORKEE GROUP.										
138	22	1954	368'-0" / 122'-0"	54	33,234	9	10,100	1,600	R	S.D. + C	The well is discharging sand in appreciable quantity. Quick worn out of pump sets. Chocking of tube and strata.
				55	31,161						
				56	31,161						
				57	27,100						
				58	23,500						
				59	15,900						
				60	23,222						
				61	19,186						
				62	17,338						
				63	19,569						
139	25	1956	319'-0" / 70'-0"	56	19,300	7	(-) 2,200	1,200	R	S.D. + C	Heavy sand discharged. Frequent break downs. Discharge in 60 was increased due to 3 stage set provided but it has again fallen down. Chocking of tube and strata.
				57	16,600						
				58	14,500						
				59	13,300						
				60	28,199						
				61	28,681						
				62	25,864						
				63	23649						

1	2	3	4	5	6	7	8	9	10	11	12
140	26	1955	375'-8" / 84'-1"	55	27,251	8	150	1,600	R	S.D.	Tho woll is discharging sand in approciablo quantity. Quick work out of pump sots.
				56	29,100						
				57	29,100						
				58	29,100						
				59	27,100						
				60	30,154						
				61	23,649						
				62	25,864						
				63	22,796						
141	27	1955	386'-6"3 / 88'-9"	55	31,161	8	5,900	1,800	R	S.D. + C	Hoavy sand and gravol dischargo. Frequont ro-pair of pumping sot. Yiol of woll going down Chocking of tubo and strata.
				56	31,161						
				57	25,412						
				58	25,412						
				59	25,412						
				60	29,167						
				61	25,412						
				62	20,348						
				63	19,569						

1	2	3	4	5	6	7	8	9	10	11	12
142	28	1955	381'-0" / 88'-9"	55	31,161	8	7,300	2,000	R	S.D. + C	Sand discharge. Frequent repairs of pumping sets. Yield going down. Ground assumed the well sinking Gravel from holes being fed. Chocking of tube and strata.
				56	29,167						
				57	27,100						
				58	21,900						
				59	21,900						
				60	25,412						
				61	23,649						
				62	21,961						
				63	19,569						
143	24		380'-0" / 105'-4"	55	23,220	8	1,400	1,900	R	S.D.	Sand discharge in small quantity , Repairs of pump required frequently.
				56	20,348						
				57	23,500						
				58	21,100						
				59	23,500						
				60	23,649						
				61	20,348						
				62	21,961						
				63	20,348						

1	2	3	4	5	6	7	8	9	10	11	12
144	87	1954	259'-6" / 80'-0"	55	27,251	8	3,400	2,100	R	S.D.	Well is discharging sand appreciable quantity. Frequent repairs of p pumping set.
				56	27,251						
				57	23,500						
				58	29,100						
				59	23,650						
				60	21,551						
				61	20,348						
				62	20,348						
				63	28,400						
145	38	1955	276'-0" / 80'-0"	55	31,161	8	2,200	2,300	R	S.D.	Well is discharging sand in small quantity . Fre-quent repairs of pumping set is required.
				56	31,161						
				57	27,100						
				58	33,200						
				59	31,100						
				60	28,681						
				61	27,251						
				62	27,251						
				63	26,200						

1	2	3	4	5	6	7	8	9	10	11	12
146	39	1954	-	54	31,161	8	5,800	2,200	R	S.D. + C	Sand is boing dischargod in excessive quantity. Cavity is formod which is boing fed by bajri. Chocking of tubo and strata.
				55	24,964						
				56	25,412						
				57	25,412						
				58	27,100						
				59	23,650						
				60	28,199						
				61	28,199						
				62	25,412						
				63	20,348						
147	41	1955	-	55	37,623	8	3,500	1,400	R	S.D. + C	Woll is discharging sand in small quantity, and tho woll is falling. Choc-king of tubo and strata.
				56	37,623						
				57	35,100						
				58	36,500						
				59	34,518						
				60	35,388						
				61	32,708						
				62	31,161						
				63	30,154						

1	2	3	4	5	6	7	8	9	10	11	12
148	45	1959	300'-0" / 117'-0"	59	47,393	4	10,000	1,200	R	S.D. + C	Well is discharging sand In 60, the ground near the well sunk due to cavity formation. Gravel is being fed sand discharge continues. Frequent repairs to pump on required.
				60	39,040						
				61	37,623						
				62	36,495						
				63	35,388						
149	46	1959	365'-0" / 104'-0"	59	31,161	3	1,300	1,200	R	S.D.	Ground assured the well is sinking and gravel is being fed. Sand discharge. Frquent repairs are required in the pumping sets.
				60	31,161						
				61	31,161						
				62	27,251						
150	13	1954	260'-0" / 81-0"	54	35,388	9	6,400	2,400	R	S.D. + C	Discharge is falling. Sand discharge in beginning. Pumping repairs required frequently Chocking of tube and strata.
				55	35,388						
				56	33,234						
				57	33,234						
				58	31,161						
				59	31,161						
				60	30,665						
				61	24,522						

1	2	3	4	5	6	7	8	9	10	11	12
				62	20,744						
				63	20,348						
161	16	1956	263'-0" / 84'-0"	56	36,495	7	4,600	2,000	R	S.D. + C	Sand discharge in the beginning. Frequent repairs are required. Discharge falling. Chocking of tube and strata.
				57	31,100						
				58	37,700						
				59	33,200						
				60	31,161						
				61	31,161						
				62	29,658						
				63	29,167						
162	21	1954	308'-0" / 104'-0"	54	35,939	9	2,600	2,200	R	S.D. + C	----do----
				55	35,939						
				56	35,388						
				57	35,939						
				58	35,939						
				59	35,388						
				60	33,234						

1	2	3	4	5	6	7	8	9	10	11	12
				61	32,188						
				62	28,681						
				63	27,251						
153	8	1955	292'-0" / 86'-0"	55	31,161	8	1,200	2,200	R	S.D. + C	Sand discharge in the beginning. Frequent repairs are required. Discharge falling. Chocking of tube and strata.
				56	31,161						
				57	33,200						
				58	31,100						
				59	31,100						
				60	29,167						
				61	33,234						
				62	23,649						
				63	21,580						
154	12	1954	328'-0" / 95'-0"	54	38,771	9	4,000	1,800	R	S.D. + C	----do----
				55	37,623						
				83	37,623						
				57	37,623						

1	2	3	4	5	6	7	8	9	10	11	12
				58	36,500						
				59	35,000						
				60	33,234						
				61	33,234						
				62	31,161						
				63	31,161						
155	9	1954	335'-0" / 90'-0"	54	38,771	9	4,800	2,200	R	S.D. + C	Slight sand discharge in beginning. Frequent pump overhaulings are required. Yield is falling. Chocking of tube and strata.
				55	39,940						
				56	39,940						
				57	33,200						
				58	33,200						
				59	31,100						
				60	27,251						
				61	35,388						
				62	33,765						
				63	32,188						

1	2	3	4	5	6	7	8	9	10	11	12
156	10	1954	358'-0" / 90'-0"	54	36,495	9	2,500	2,000	R	C	The yield from the well has slightly gone down.
				55	35,388						
				56	35,388						
				57	33,200						
				58	31,100						
				59	36,495						
				60	35,388						
				61	34,301						
				62	33,765						
				63	21,161						

1	2	3	4	5	6	7	8	9	10	11	12
DEO BAND GROUP.											
157	4	1955	326'-8" / 89'-6"	55	31,161	8	1,900	3,600	R	S.D. + C	Discharging sand in the begining for about 10 minute. The yield has now cons-derably fallen. Chocking of tubes and strata.
				56	28,681						
				57	31,161						
				58	32,188						
				59	32,188						
				60	31,161						
				61	28,199						
				62	27,251						
				63	23,648						
158	8	1955	334'-4" / 84'-0"	55	35,388	8	3,100	3,400	R	C	Yield from the well has slightly decreased Chocking of tubes and strata.
				56	31,161						
				57	31,161						
				58	32,188						
				59	36,145						
				60	33,243						
				61	32,188						
				62	31,161						
				63	31,161						

1	2	3	4	5	6	7	8	9	10	11	12
159	14	1955	355'-3" / 95'-1"	55	30,600	8	900	3,100	R	S.D. +	Discharging/sand in smalle quantity .
				56	29,167						
				57	28,199						
				58	30,154						
				59	33,234						
				60	32,188						
				61	30,154						
				62	27,251						
				63	27,251						
160	15	1955	279'-2" / 98'-10"	55	31,161	8	900	3100	R	S.D.	Dischargin sand in small quantity.
				56	31,162						
				57	27,722						
				58	31,161						
				59	32,188						
				60	31,161						
				61	29,167						
				62	31,161						
				63	28,199						

1	2	3	4	5	6	7	8	9	10	11	12
161	16	1955	352'-3" / 96'-0"	55	37,623	Q	(-) 100	2,800	R	S.D.	Discharging sand. Frequent ropairs are required. A new set was providad in 1959.
				56	37,623						
				57	32,188						
				58	33,234						
				59	38,940						
				60	41,129						
				61	41,129						
				62	39,940						
				63	37,623						
162	17	1955	342'-2" / 93'-8"	55	37,623	8	4,000	2,500	R	S.D. + C	Well is discharging sand in small quantity at start for abor about 15 minutes. Yiel has considerably reduced Chocking of tubes and strata.
				56	37,623						
				57	34,842						
				58	32,188						
				59	37,623						
				60	35,388						
				61	34,301						
				62	29,167						
				63	28,199						

1	2	3	4	5	6	7	8	9	10	11	12
163	18	1955	295'-11" / 107'-2"	55	31,161	8	800	2,300	R	S.D.	Slight sand discharge Frequent repairs are required.
				56	31,161						
				57	31,161						
				58	28,199						
				59	31,161						
				60	32,138						
				61	30,107						
				62	31,161						
				63	28,199						
164	21	1955	292'-0" / 93[illegible]'-0"	55	31,161	8	(-) 1,100	2,100	R	S.D.	Discharging fince sand in the beginning. Frequently. Repairs are required.
				56	31,161						
				57	31,161						
				58	32,188						
				59	35,388						
				60	35,388						
				61	33,234						
				62	32,188						
				63	31,161						

1	2	3	4	5	6	7	8	9	10	11	12
165	25	1954	-	55	39,658	8	11,400	2,200	R	S.D. + C	Heavy sand discharge. Frequent heavy repairs are required. Discharge falling. Chocking of tube and strata.
				56	39,658						
				57	29,100						
				58	31,100						
				59	31,100						
				60	29,167						
				61	23,649						
				62	21,961						
				63	20,348						
166	26	1954	-	55	27,251	8	1,800	2,400	R	S.D.	Sand discharge continiously. Well discharges clay also in the beginning. Discharge is falling.
				56	23,649						
				57	29,100						
				58	29,100						
				59	25,774						
				60	24,522						
				61	23,220						
				62	23,649						
				63	23,649						

DISTRICT - ALIGARH

6" SLOTTED PIPE TUBE-WELLS

1	2	3	4	5	6	7	8	9	10	11	12
ALIGARH GROUP.											
167	57	1953	141'-0" / 40'-0"	53	20,300	8	2,300	2,600	A	S.D. + C	From the very start, the well gave sand and clay which increased gradually Abondoned due to uneconomical running. Chocking of strata and slots .
				55	23,649						
				57	14,412						
				58	20,348						
				59	17,338						
				61	14,500						
168	55	1951	155'-0" / 40'-0"	51	24,938	8	6,600	3,400	A	C	In the yield of the well reduced to 14,500 g.p.h Back washing and sludging did not improve. Chocking of strata and slots.
				53	20,300						
				60	20,300						
				61	14,500						
169	37A	1957	126'-0" / 60'-0"	57	31,161	5	4,400	4,300	B	C	Discharge from the well has gone down. Chocking of slots and strata.
				58	27,251						
				60	25,300						
				61	27,251						
				62	27,251						

1	2	3	4	5	6	7	8	9	10	11	12
170	7R	1955	362'-0" / 69'-0"	55	35,388	8	-	2,100	R	-	There is no trouble at present.
				58	35,388						
				61	36,500						
				62	36,500						
				63	36,500						
171	21N	1955	141'-0" / 47'-0"	55	39,940	8	3,400	1,800	R	-	---do----
				56	35,388						
				58	35,388						
				61	39,940						
				63	35,388						
172	1 N.E.S. JAWAN	1959	311'-3" / 99'-3"	59	35,388	4	-	1,600	R	-	----do---
				60	37,200						
				61	37,200						
				62	37,200						
				63	35,388						
173	2 N.E.S. JAWAN	1930	402'-0" / 98'-5"	60	36,500	3	-	1,800	R	-	----do-----
				61	36,500						
				62	39,800						
				63	36,500						

1	2	3	4	5	6	7	8	9	10	11	12
	HATHRAS GROUP.										
174	25	1955	-	55	31,161	3	13,300	1,900	A	DISLOCATION OF PIGS.	In 56, the pipe assembly sandk. Yield reduced to 23649 g.p.h. In 58, pit collapsed and yield further reduced. Failure due to dislocation of pipes.
				56	23,649						
				58	12,158						

1	2	3	4	5	6	7	8	9	10	11	12
	MATHURA DISTRICT.										
175	1	1956	380'-0" / 71'-3"	58	26,326	5	2,900	-	R	C	There is no trouble at present except the yield has slightly fallen down. Chocking of slots and strata.
				59	25,864						
				60	23,649						
				61	23,649						
				62	23,649						
				63	20,348						

1	2	3	4	5	6	7	8	9	10	11	12
	ATRAULI GROUP.										
176	130	1952	278'-0" / 70'-0"	53	29,100	10	2,600	2,000	R	C	There is no trouble at present. Except the yield has slightly fallen down. Chocking of slots and strainer.
				55	23,500						
				57	23,500						
				58	29,167						
				59	29,167						
				60	27,100						
				62	27,100						
				63	25,864						
177	71R	55	456'-0" / 82'-0"	56	35,388	7	800	1,700	R		---do---
				57	35,388						
				59	33,234						
				61	33,734						
				62	35,388						
				63	35,388						
178	61R	1957	465'-0" / 96'-3"	57	33,200	6	-	1,300	R	-	There is no trouble at present

1	2	3	4	5	6	7	8	9	10	11	12
				58	33,200						
				59	35,400						
				61	35,400						
				62	35,400						
				63	35,400						
179	118R	1956	465'-0" / 96'-0"	56	33,234	7	-	1,400	R	-	There is no trouble at present.
				57	33,234						
				59	33,234						
				61	33,234						
				62	33,234						
				63	33,234						

DISTRICT-DEHRADUN

6" SLOTTED TUBE-WEELS.

1	2	3	4	5	6	7	8	9	10	11	12
180	1	1959	-	59	23,220	4	(-)	125	R	-	The well is running satisfactorily.
				60	23,649						
				61	18,064						
				62	28,199						
				63	27,251						

APPENDIX "C"

Sieve test data of samples of sands from 15 stratas of wells of various districts is shown in the accompanying table. All these wells were provided with 6" Agricultural strainer type of screen.

Out of these 15 samples, cumulative sand analysis curves of 12 stratas have been shown in figs. 3.43A, 3.43B and 3.43 C. A large percentage of fine uniform sand is revealed in case of the following samples:

T.W.No. 4,11,74 and 76 - Dist. Aligarh

T.W.No. 30(B), 62,63 and 108-Dist. Meerut

T.W.No. 1(A) -Dist.Muzaffarnagar

There are no coarse particles in the samples. This type of sand is relatively poor water producer and will be best developed by artificial gravel treatment.

Cumulative sand curve of T.W.No. 66 - Dist. Aligarh (Fig.3.43A) reveals a fine uniform sand with a small percentage of coarse particles. A careful selection of screen openings and proper development work is required. Gravel treatment is not necessary but it will be advantageous if properly done.

Cumulative sand curves of T.W. No. 30(A) and 30(B) - Dist. Meerut show a well graded sand with low percentage of fine particles. This formation if properly developed will provide a natural treatment. This type of formation do not require gravel treatment at all.

Figure 4.41 shows % retaining sand analysis curves of 6 strata samples on a semi log graph paper. All of these stratas were provided with 6" Agricultural type of strainer. But from graph, it will be seen that all of these samples have a large percentage of fine uniform sand and, therefore, are not suitable for screens.

Artificial gravel treatment is necessarily required for them for full development and yield.

Design of artificial gravel pack for strata of T.W. South Loi (A) is given in figure C_1 attached.

SIEVE TEST DATA OF WELLS

TABLE - I

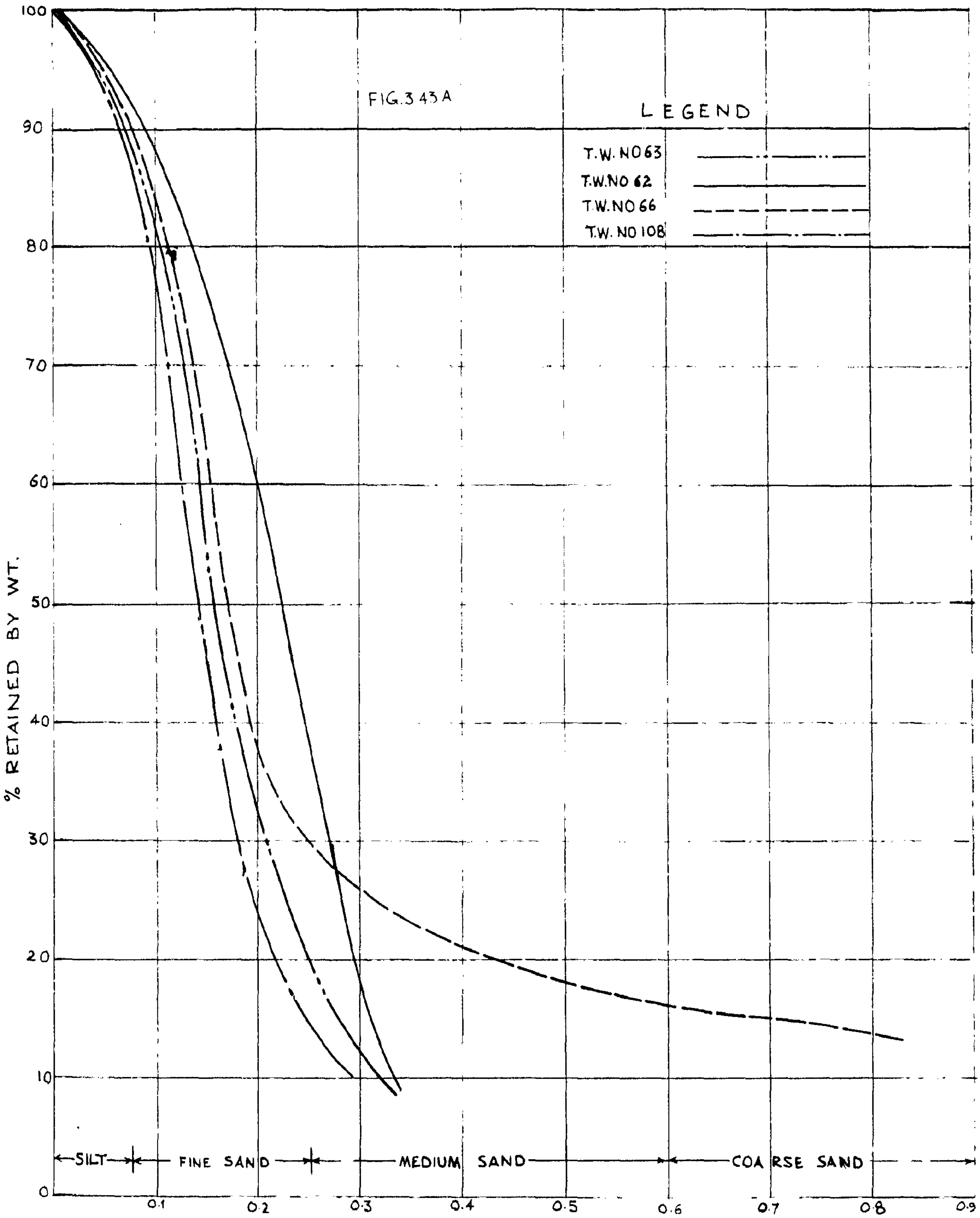
Sl. No.	Sample of Sand from T.W. No.	Division & Group	D_{10} m.m.	D_{50} m.m	D_{60} m.m	D_{85} m.m	Uniformity coefficient D_{60}/D_{10}
1	62	Aligarh(Atrauli)	.09	0.23	0.25	0.31	2.78
2	66	-do-	.082	0.175	0.19	0.72	2.36
3	108	-do-	.069	0.145	0.16	0.25	2.32
4	63	-do-	.075	0.16	0.18	0.28	2.4
5	63	-do-	.07	0.17	0.19	0.27	2.71
6	74	-do-	.071	0.265	0.285	0.4	4.01
7	76	-do-	.08	0.21	0.23	0.3	2.87
8.	1	Aligarh(Morhar)	0.12	0.253	0.266	0.39	2.22
9	4	-do-	.065	0.16	0.16	0.19	2.61
10	15	-do-	0.12	0.185	0.19	0.268	1.58
11	11	-do-	0.16	0.26	0.28	0.36	1.75
12	30	Meerut(Daha)A	0.095	0.23	0.27	0.4	2.84
13	30	-do- B	0.23	0.37	0.42	0.67	1.82
14	1	Muzaffarnagar (South Loi)A	0.135	0.23	0.25	0.36	1.85
15	1	-do- B	0.27	0.42	0.47	0.75	1.74

LIST OF SICK WELLS ON WHICH CHEMICAL OR CALGON TREATMENT (CHAPTER V) CAN BE TRIED AFTER TEST.

TABLE II

SL. NO.	6" AGRI. STRAINER WELLS T.W. NO.	INITIAL SPECIFIC DRAW-DOWN G.P.M.	LATEST SPECIFIC DRAW-DOWN G.P.M.
	MEERUT GROUP		
1	20	23.3	18.4
2	18	24.1	20.3
3	24	31.5	18.0
4	28	37.3	19.9
5	33	40.6	23.8
6	35	40.8	24.5
7	54	62.3	49.1
8	53	64.0	47.5
	LOHARA GROUP		
9	32	57.1	44.3
10	40	31.0	27.9
	SOUTH LOI GROUP		
11	9R	22.7	18.8
12	16R	29.9	24.0
13	14R	21.8	16.9
	JANSATH GROUP		
14	6	27.6	16.4
15	7	31.6	10.1
16	13	24.8	14.2
	ROORKEE GROUP		
17	5	45.3	16.6

SL. NO.	6" SLOTTED TUBE TYPE WELLS. T.W. NO.	INITIAL SPECIFIC DRAW-DOWN G.P.M.	LATEST SPECIFIC DRAW-DOWN G.P.M.
	SAHARANPUR GROUP		
1	16	15.6	13.5
	NAKUR GROUP		
2	41		
3	48	44.1	33.0
	ROORKEE GROUP		
4	22	55.3	13.5
5	26	45.4	31.6
6	28	23.5	13.0
7	39	25.3	13.0
8	41	36.9	25.1
9	46	32.4	18.1
10	13	53.6	14.1
11	21	54.4	32.4
12	8	74.2	35.9
13	12	32.3	16.2
14	10	50.6	24.7
	DEOBAND GROUP		
15	15	30.5	26.8
16	16	41.8	31.3
17	25	36.7	15.4
18	30	46.7	32.4
	DAHA GROUP		
19	21	36.1	31.3
	MUZZAFAR NAGAR GROUP		
20	14	53.6	46.1
21	17	53.6	47.2

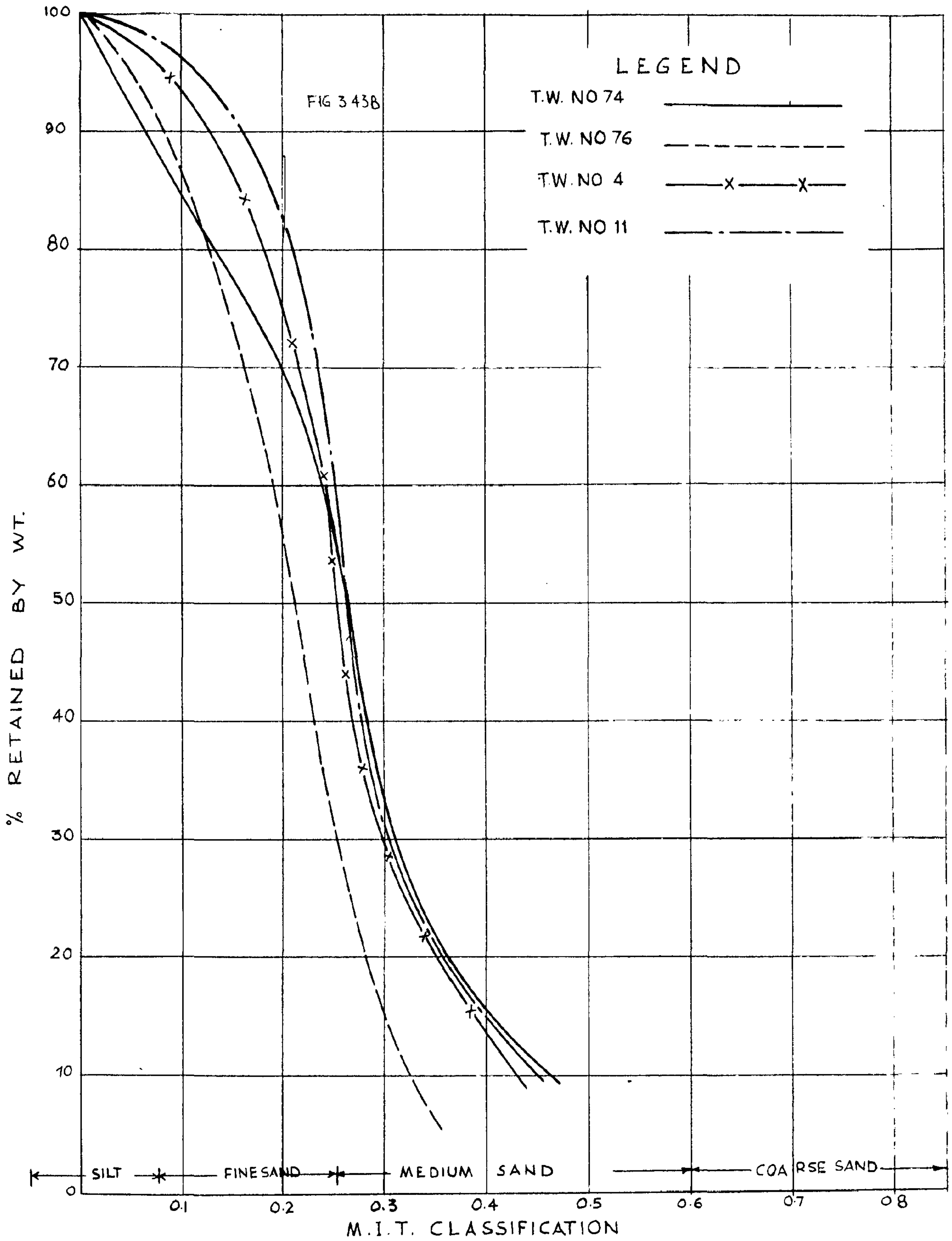


M.I.T. CLASSIFICATION

CUMULATIVE CURVE OF SAND ANALYSIS

SAND SIZE IN M.M.

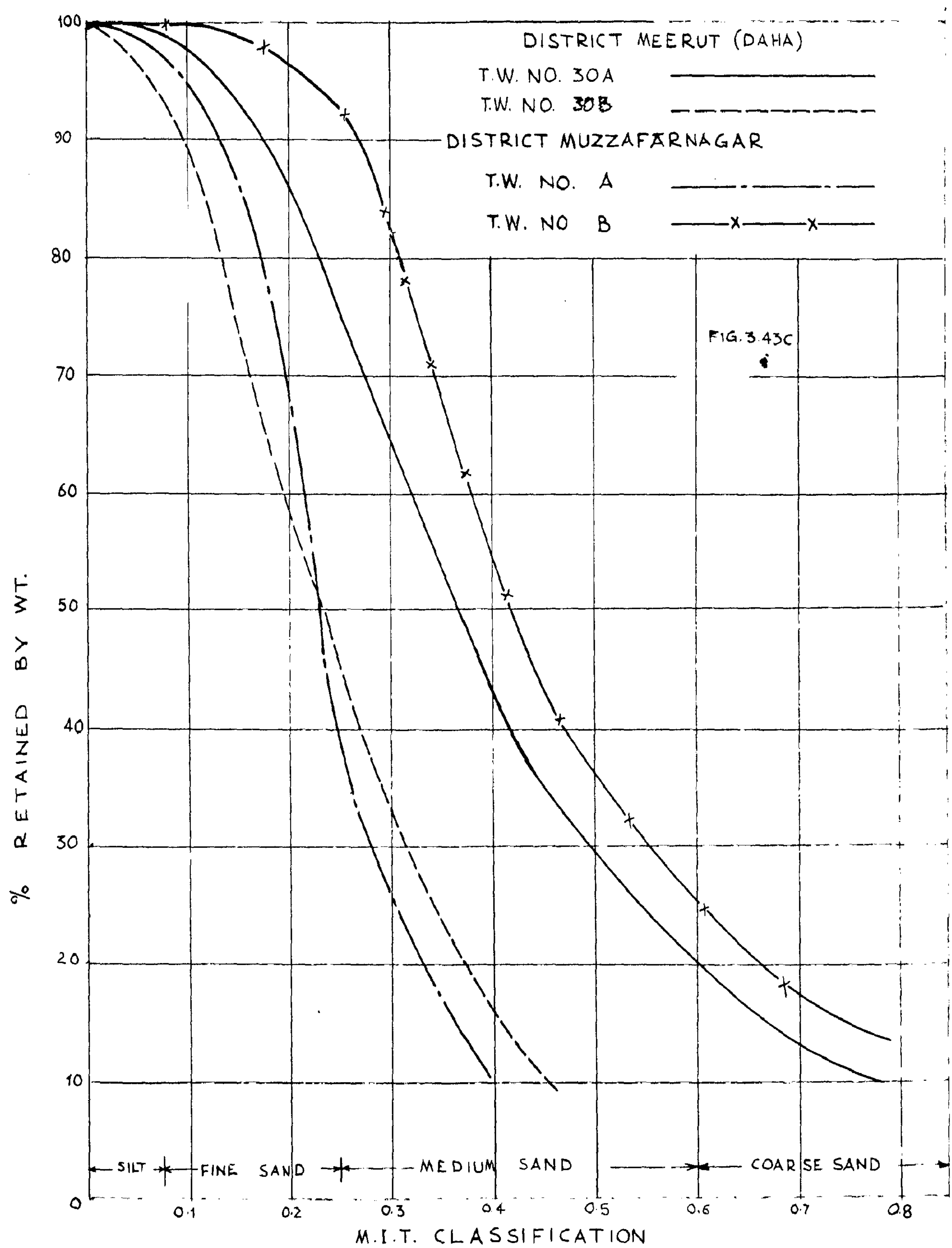
DISTRICT ALIGARH (ATRAULI)



CUMULATIVE CURVE OF SAND ANALYSIS

SAND SIZE IN M.M.

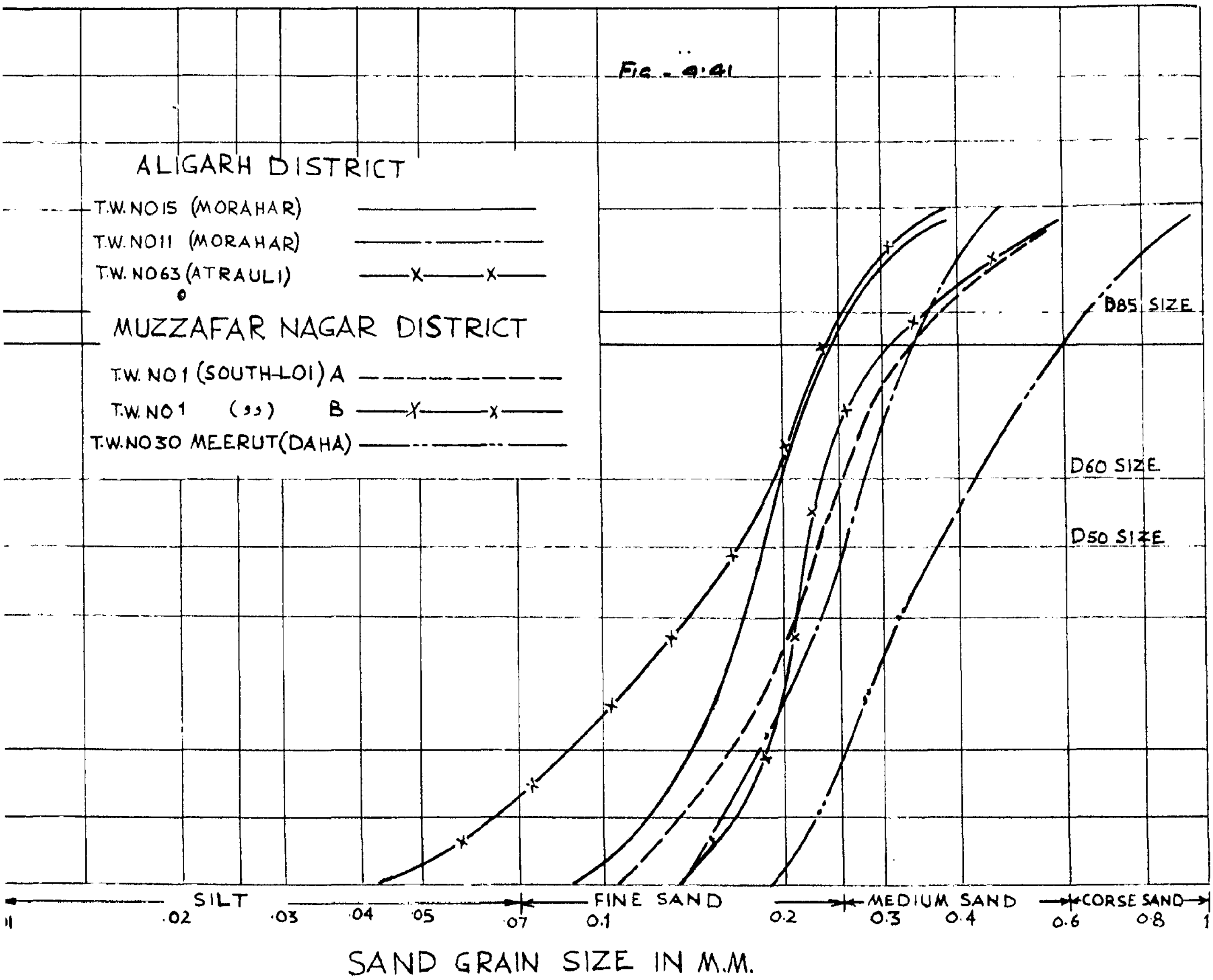
FIG. 3.43 B DISTRICT ALIGARH (ATRAULI & MORAHAR)

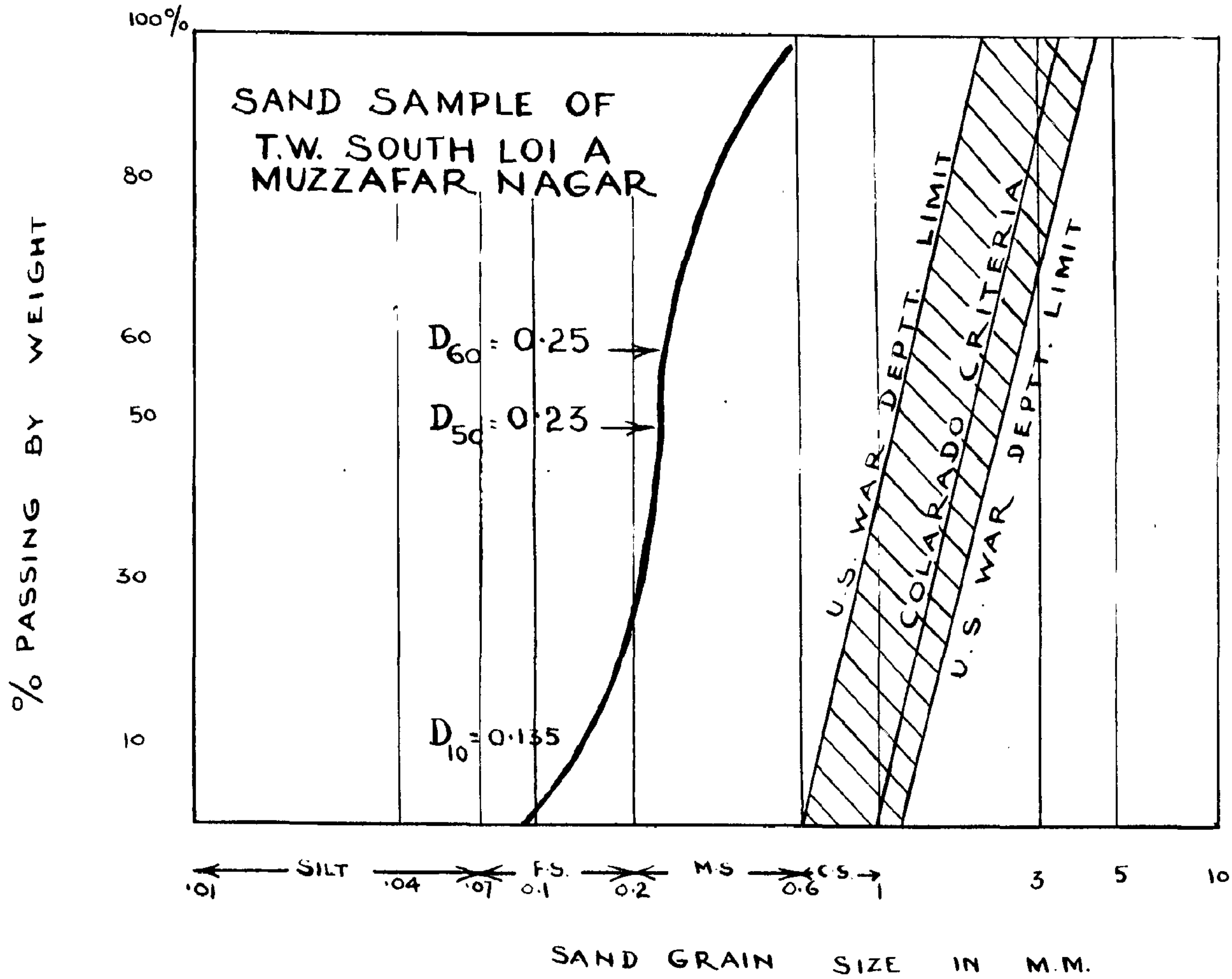


CUMULATIVE CURVE OF SAND ANALYSIS

FIG. 3.43 C SAND SIZE IN M.M.

Fig. 4.41


ALIGARH DISTRICT
T.W. NO15 (MORAHAR)
T.W. NO11 (MORAHAR)
T.W. NO63 (ATRAULI)
MUZZAFAR NAGAR DISTRICT
T.W. NO1 (SOUTH-LOI) A
T.W. NO1 (,,) B
T.W. NO30 MEERUT(DAHA)
D85 SIZE
D60 SIZE
D50 SIZE
SILT
FINE SAND
MEDIUM SAND
CORSE SAND
.02
.03
.04
.05
.07
0.1
0.2
0.3
0.4
0.6
0.8
1
SAND GRAIN SIZE IN M.M.



COLARADO CRITERIA

AQUIFER	U.C	GRAVEL	U.C.
D50 = 0·23	1·8	D_{50} = 0·23 x 8 = 1·84	2·1/1·1 = 1·9

U.S WAR DEPTT. CRITERIA.

GRAVEL LIMIT

D_{50} X 0·5 = 0·23 x 5 = 1·15

D_{50} X 10 = 0·23 x 10 = 2·3

APPENDIX "D"

RECENT TECHNIQUES OF DRILLING DEEP WELLS

For construction of large capacity wells, besides hand boring, three following methods of drilling are generally employed now a days:

(1) Cable tool method.

(2) Hydraulic rotary method.

(3) Reverse Rotary method.

Out of the above three methods, the cable tool method is most common whereas reverse rotary type is a more recent technique. The construction procedure of a deep well, however, largely depends upon local conditions encountered in drilling and therefore each well has got its own individuality and therefore must be handled as such.

CABLE TOOL METHOD: In this method percussion drilling is employed with the help of a boiler. The hole is drilled by raising or lowering a heavy bit on the end of a steel cable which is threaded over a sheave at the top of the mast and down to the drill line drum of the percussion rig machine. The broken and crushed material in the bottom of the hole is removed by means of a boiler or sand pump. The oscillating tool produces a jar which can be felt by the operator. Each formation has its characteristic jar. The character of the jar indicates the manner in which tool is operating. The driller regulates the length of stroke and rapidity of blows according to his interpretation of the vibrations conveyed to him through the drilling cable.

Different types of bits and their cutting edges are used for consolidated and unconsolidated aquifers. Club drill bit is the most common type and can be used with reasonable success in almost every type of formation. The edges of the bit are either sharp or blunt for consolidated or unconsolidated formation respectively. The bit is made of heavy steel bar 4 to 11 feet long. The shank of the bit is several inches smaller than the cutting edge and a wide groove is provided on each side of it to permit easy displacement of the fluid as the tool oscillates in the bore.

<u>ADVANTAGES</u>: The advantages of cable tool method are:-

(1) More accurate sample of formation is obtained.

(2) Quantity and quality of each stratum can be tested as drilling proceds.

(3) The cable tool rig is much lighter and can be easily transported.

<u>ROTARY TEST DRILLING</u>:- A rotary drill is a most useful tool for test hole work. Rotary drilled test holes produce more information than any thing else. The test holes are generally of 4-4½ inch diameter. While drilling a best hole the following information is carefully recorded, about the formation:

(1) Depth drilled.

(2) Eate of drilling.

(3) Behaviour of drilling tools.

(4) Formation Sample.

(5) Thickness of each stratum.

(6) Record of static water cable.

(7) Weight of mud.

(8) Loss of mud.

(9) Viscosity of mud.

(10) Accurate sample of water is the formation.

Though quite a lot of information is available during cable tool drilling but several items of the above list are only possible when the test hole is drilled by a rotary rig. For example, a formations which absorb fluid during rotary drilling are porous and of sufficient permeability to give up water when pumped. The data so collected at site is then sent to experts who analyse it and makes a correct interpretation. In an unknown area where a new tube-well scheme is required to be introduced, rotary, test hole drilling is most efficient and comparatively cheap than any other method.

HYDRAULIC-ROTARY DRILLING: The hydraulic rotary method is the fastest method of drilling a hole in an unconsolidated formation. In this method no casing is required. The mud used forms a clay lining on the wall of the well which prevents caving. The hole is made by the rapid rotation of a bit on the bottom of a string of drill pipe. The cuttings are removed by circulation of mud fluid descending through the drill pipe and ascending outside the pipes. The broken fragments of formation are brought to the surface in suspension where in a tank they settle out and the mud is recirculated after mixing necessary amount of water and clay to maintain quantity and consistency.

The drilling machine is rigged up at site. The drilling bit is attached to the drill pipe which is screwed on to the end of kelly - a square section of drill pipe which fits into the rotary table on the derric floor of the rig machines.

The amount of weight placed on the bit is increased or decreased according to formation which may be sandy or sticky.

The most common type of rotary drilling bit is known as fish tail bit which may very in length from 15" to 2' or 4 feet. It is generally made of chrome steel formed into a tapering double wing blade. To give a screw effect during rotation the two wings of the bit are alightly turned back in opposite direction. The use of this type of bit is very effective in soft formation but should be avoided in hard materials where it gets dulled very quickly.

ADVANTAGES : The important advantages of a hydraulic rotary method are :-

(1) Large heles upto 60 ich. diameter can be drilled.

(2) In an unknown area, a small test hole can be drilled very quickly and economically. If the prospects are poor, the hole, can be abondened without the troubles of pulling the casing or leaving some other material in the hole.

(3) Suitable casing can be located at the desired depth. This ensures maximum supply, minimum draw-down and minimum inflew velocity, which decreases sand troubles.

(4) It can handle, alternate layers of hard and seft formations with less accidents.

One of the most important item of hydraulic rotary drilling is the washing of formation after the complete hole has been drilled. If the mud is not completely washed, it will not allow full yield of the formation to be pumped out (refer para 4,32 to 4,37).

REVERSE ROTARY: It is a modification of hydraulic rotary method and has become extremely popular in Europe and U.S.A. In reverse rotary drilling no casing is required as in the case of hydraulic rotary method. Instead as the drilling proceeds, a thin film of fine-grained material of the cutting is deposited on the interior of the bore which is the weeping surface of the producing zone of formation. This thin membnrane together with a differential head of at least 6 to 10 feet between the water table and liquid level in the bore is sufficient to stalilise the walls of the well during drilling. There is no need of adding clay or any foreign material during construction.

The hole is drilled by attaching a cutting face or hit to the hollow drill pipe, which is rotated by a power table. The loosened unconselidated material is removed from the bore under construction in a stream of water which carries it up the below drill pipe and into a tank where it is settled out and the fines in suspension are recirculated with water which returns to the bottom of the bore and thus cycle is completed. It is essential that tank and bore are kept full of fluid at all times.

Nature of formation guides the rate of drilling by a reverse equipment. Laminated clays or very heavy compacted clays with embedded boulders are troublesome in drilling. Laminated clays do not takes water and therefore are more likely to cave in.

Before a reverse rotary drilling is undertaken, the following essential conditions must be fulfilled because the drilling once started can not be stopped:

(1) There must be an ample supply of water.

(2) Accurate test hole data must first be obtained and

should be available at site.

(3) Proper screen with all fittings must be on the site before drilling is begun.

(4) Gravel packing of the proper grade must be available in sufficient quantity for a gravel pack well.

(5) Clay and well casing must be available at short notice, if it becomes necessary to use them.

(6) Proper plan must be chalked out to work around the dock.

ADVANTAGES: The advantages of the reverse circulation method of construction are manifold:

(1) A larger diameter bore can be drilled resulting in larger weeping surface areas.

(2) Drilling is comparatively easy in deep sands and gravel formations.

(3) It gives a more clean cut weeping surface in the well bore particularly in laminated formation.

(4) The well is sufficiently developed during test pumping only.

(5) Reverse circulation rotary drilling method generally costs less than other methods.

COMPARATIVE DRILLING PERFORMANCE: The following table taken from War Department Technical Manual 7-M-5-297 of the United States Government gives an idea of the relative performances of the percussion and rotary rigs.

7

Type of formation	Relative Drilling Performance	
	Rotary Drill.	Percussion Drill.
Dune Sand	Rapid	Difficult to impossible.
Loose Sand and Gravel	Rapid	Difficult to impossible.
Quik Sand	Rapid	Difficult to impossible except in thin stratas
Clay and Silt	Rapid	Slow
Firm shale	Rapid	Rapid
Sticky Shale	Rapid	Slow
Brittle Shale	Rapid	Rapid
Sand Stone-Well Cemented	Slow	Slow
Sand Stone poorly cemented	Slow	Slow
Lime-Stone	Rapid	Rapid
Lime Stone with small cracks or fractures	Slow	Rapid
Dolomite	Same as lime stone.	Same as Lime Stone.
Basalt, thin layers in sedimentary rocks	Slow	Rapid
Basalt thick layers	Slow	Slow
Granite	Slow	Slow.

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