Technology Mission on Drinking Water in Villages & Related Water Management

PROCEEDINGS

CHIEF ENGINEERS' CONFERENCE

JULY 28-29, 1987

NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE,
NEHRU MARG, NAGPUR-440020.

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TECHNOLOGY MISSION ON DRINKING WATER IN VILLAGES AND RELATED WATER MANAGEMENT

Proceedings

Chief Engineers' Conference

July 28-29, 1987

Editors : J. S. Gadgil
R. K. Saraf

Convener : Dr. K. L. Saxena

NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
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F O R E W O R D

The Water Technology Mission, with the responsibility of provision of drinking water to entire village population by the end of 1990, the year the International Water Supply and Sanitation Decade concludes has been functional for about two years.

With such a gigantic task at hand and with the diversity of problems like excess of fluoride or iron in water sources, guinea-worm infestation, etc., it was considered worthwhile to have a get-together where the policy makers, the Chief Engineers and the personnel in the field could meet, discuss their experiences to overcome the problems and make good the short-comings for timely completion of mission objectives.

NEERI, accordingly, hosted a Chief Engineers' Conference on July 28 and 29, 1987 at Nagpur. The Conference was attended by Chief Engineers from 20 States and Union Territories as also a sizeable number of field workers besides the planners. The participants were exposed to details of work being concluded by NEERI on slow sand filtration, iron and fluoride removal, disinfection as also on planning and design of minimal cost rural water supply systems.

This Volume incorporates the Proceedings of the Conference as also the Recommendations made by the Delegates at the Conference.

I take this opportunity to thank all the participants as also the NEERI Staff who put in their best to make the Conference a success. I wish to express special appreciation of the efforts made by Mr. K.R. Bulusu, Scientist & Coordinator, WTM in organising the Conference and Mr. S.G. Bhat, Scientist in bringing out the proceedings.

Khanna

(P. Khanna)
DIRECTOR

Nagpur
November 30, 1987

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WELCOME

Prof. P. Khanna

Director, NEERI

Water Technology Mission Director Mr. Gauri Ghosh, Chief Engineer Mr. Inamul Haq, distinguished Chief Engineers/delegates/invitees, media men and my colleagues: I accord you a very warm welcome, with lowered ambient temperature but with a warm heart, on the occasion of the Chief Engineers' Conference on Water Technology Mission.

It would not be out of place for me to trace the events that led to the launching of WTM. It was in 1981 that the Government of India became a signatory to International Drinking Water Supply and Sanitation Decade and established its targets for the Decade. The IDWSSD, as you are aware, is a forerunner to another target, Health for all by 2000 AD. The target fixed for IDWSSD in 1981 was 100 percent coverage of rural water supply by 1990 from 1981 coverage of 30 percent at an expenditure of Rs.4,200 crores. The mid-decade evaluation by the Government of India revealed a backlog of 2.27 lakh problem villages in the area of water supply. This, to my mind, led to the launching of the Water Technology Mission (WTM). The key words in the implementation of WTM are cost-effectiveness with recourse to S&T inputs.

The problem villages are identified as ones where either the water is not available at a reasonable distance or depth, or there is the problem of chemical or biological contamination. The functionality of the systems; which is measured in terms of adequate quantity, quality and distance of the source and reliability of supply; must be achieved through cost-effective solutions.

Traditionally, rural water supply systems (RWSS) are treated as scaled-down versions of urban water supply systems warranting less engineering skill and ingenuity in design. Nothing can be farther from the truth. RWSS are essentially dead-end systems catering to lower population densities warranting innovative design procedures. The conventional methods of design neither ensure functionality nor cost-effectiveness. The gamut of rural water supply essentially comprises in identification of a perennial source of water, conveyance of water, purification of water, and its distribution to the consumers either through a hand-pump, pump and tank, or regional water supply scheme. It is our contention that a slight modification in the design procedures would ensure both functionality and cost effectiveness. This system hardware must necessarily be supported by effective software on operation and maintenance, community participation and health education.

The Mission Directorate has been established in Department of Rural Development, Ministry of Agriculture, Government of India. The objectives of WTM are sought to be achieved through a multi-institutional cooperative endeavour including Non-Government Organisations. The CSIR has to provide major technological inputs in this national mission. NEERI's charter relates to the technologies for the removal of turbidity, iron, fluoride and bacteriological contamination for which the Institute has developed proven and time-tested technologies. Now, the delivery system is to be deliberated in these two days. We are willing to provide additional inputs as may be sought from the Mission Directorate and State Governments.

What has NEERI done since the launching of WTM last year? We have developed an Internal Action Plan to ensure coordination between several Divisions and Zonal Laboratories of NEERI involved in WTM. We have assessed water quality in 500 villages identified by the Mission Directorate. We have prepared Technology Information Packages (TIPS) on issues under NEERI's charter in WTM. We have conducted two National Camps on Removal of Fluorides and Iron in Gujarat and Tripura respectively. We have conducted two specialized training programmes on WTM. We have identified six demonstration sites in three States, conducted treatability studies, designed the systems and taken up the process of

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Mr. Gauri Ghosh, Mission Director and Joint Secretary, Ministry of Agriculture, Govt. of India, releasing the Institute's Technology Information Package.

Prof. P. Khanna, Director, NEERI, welcoming the delegates.

implementing these systems. We have prepared audio-visual aids for effective dissemination of cost-effective water purification technologies.

What do we propose to do in future? Our portable kits for water quality assessment based on the latest state-of-art analytical methods will be ready for commercial exploitation by December 1987. We have scheduled training programmes at demonstration sites. We propose to conduct short technology awareness camps at selected sites in the country. We shall endeavour to provide cost effective solutions to the dreaded problem of guinea worm and brackishness in near future.

The question why this Conference by NEERI must be addressed now. The charters of Public Health Engineering Departments and this Institute have always ensured close cooperation in the past and WTM is not an exception. We have assembled here essentially to discuss the problmes that the State Governments are facing in meeting the targets of WTM, help generate time-bound programmes and evolve strategies for cost-effective delivery systems.

While it is for CSIR and Mission Directorate to judge whether this Institute has come up to their expectations in WTM, let me assure you that our scientists are more than eager to leave their ivory towers, go to the field, demonstrate the technologies and work hand in hand with the State Government officials and beneficiaries.

It is my pleasant duty to welcome you to this Institute and hope that your stay here proves fruitful and rewarding. Thank you for responding to our invitation.

INTRODUCTION TO WATER TECHNOLOGY MISSION

K.R. Bulusu,

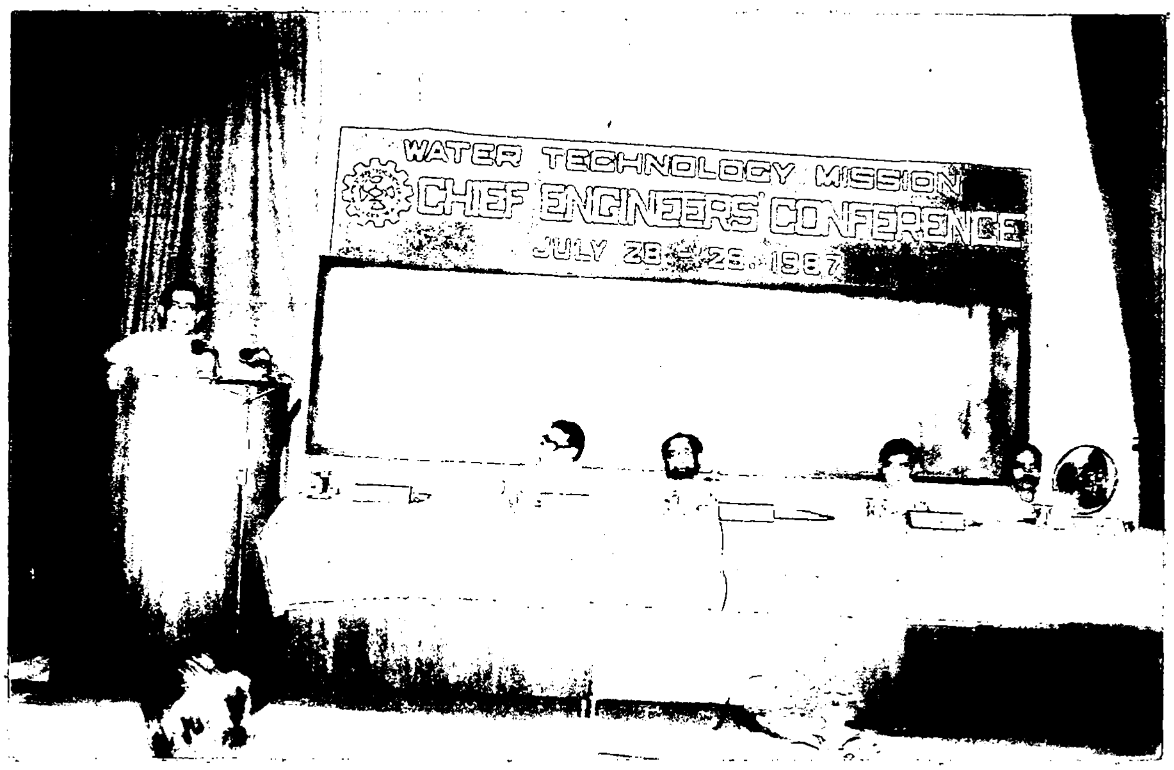
Deputy Director, NEERI

The "Technology Mission for Drinking Water in Villages and Related Water Management" has been launched by the Government of India to supplement the efforts of State Governments in the accelerated rural water supply programme aimed at providing safe drinking water facilities to the entire rural population. The primary objective of the Technology Mission is to improve the performance and cost-effectiveness of the ongoing rural water supply programmes so as to ensure the availability sustained on a long term basis.

The Mission will adopt an integrated and interdisciplinary approach to deal with specific water quality problems such as salinity, iron, fluoride, biological contamination, disinfection, etc., and scientific ground water management. This will be achieved through pilot projects by the application of all available scientific and technological inputs from various CSIR laboratories and other institutions in a coordinated manner.

The Mission strategy is to evolve model systmes which can be easily replicated and incorporated in the ongoing water supply programme. The systems will be so located all over India as to be representative of the problem villages generally encountered in providing potable water.

In the first phase of the Mission (1986-87), eleven districts have been identified for implementation; and in the 2nd and 3rd phases, 12 and 28 districts will be taken up respectively so as to cover 51 districts during the VII Plan period.



Mr. K.R. Bulusu, Deputy Director, NEERI and Coordinator, Water Technology Mission (WTM), presenting An Overview of the WTM.

Mr. P.R. Kulkarni, Chief Engineer, Maharashtra Water Supply & Sewarge Board, Bombay, presiding over the Technical Session on Slow Sand Filtration. Mr. R. Paramasivam, Scientist, NEERI, addressing the Session.

GOAL

* To supplement the efforts of State Governments in the Accelerated Rural Water Supply Programme aimed at providing safe drinking water facilities to the entire rural population

WORKING

* Department of Rural Development as the Nodal Agency has State Governments, Council of Scientific & Industrial Research (CSIR), Ministry of Science & Technology, Ministry of Health & Family Welfare, Department of Defence Research & Development, Ministry of Water Resources and Others as Collaborating Agencies

In 1985-86, the Base Year, of the total 5.75 lakhs villages, Non-problem villages numbered 3.84 lakhs (61%) and problem villages were 2.27 lakhs (39%).

A Problem Village is defined as one with

i) No source or Water source more than 1.6 km distant, or 15 m depth, or 100 m elevation difference ; and/or

ii) Biological Contamination by Guinea Worm or Cholera or Typhoid organisms; and/or

iii) Chemical contamination; Fluoride, Iron or Brackishness

MISSION OBJECTIVES

* Cover 2.27 lakh residual problem villages by 1990, 39% of total villages
* Supply 70 Lpcd in desert areas
* Supply potable water (40 Lpcd) in all other areas

* To evlove cost effective technology mix to achieve these objectives
* Take conservative measures for sustained supply of water

MAJOR PROBLEMS

* Source finding	1,54,300 villages (68%)
* Biological contamination	43,600 villages (19%)
* Chemical contamination	29,100 villages (13%)

STRATEGY

For visible results focus on submissions (countrywide)

* Eradication of guinea worm	9,920 villages by 1989
* Control of fluorosis	8,700 villages by 1989
* Control of brackishness	17,500 villages by 1990
* Removal of excess iron	2,900 villages by 1988

* To focus 50 project areas (Mini-Missions) to evolve new cost effective S&T techniques.
* To replicate and simultaneously apply these techniques for the rest of the problem villages
* Integrated approach for water conservation

ACTION

i) The desalination problem will be tackled by Central Salt & Marine Chemicals Research Institute (CS & MCRI). Bhabha Atomic Research Centre (BARC) and Defence Research Laboratory (DRL) are entrusted with working for cost-effective solutions, training of trainers and operators, supply of hardware, installation.

ii) National Environmental Engineering Research Institute (NEERI), Public Health Engineering Department (PHED), and Department of

Rural Development (DRD) will be involved in Training of users, Training of PHED staff, Fabrication and supply of equipment and Installation as far as 'Defluoridation' is concerned.

iii) For Iron Removal, NEERI and PHED shall arrange Training of PHED staff, Fabrication and supply of equipment, and Installation.

iv) Training of Trainers will be arranged for operating techniques of slow sand filtration.

v) Training to users and user agencies and village artisans for matters concerning pot chlorination will be organised.

vi) Free distribution of chlorine tablets in hilly/tribal areas, etc., will be done

vii) For eradication of guinea worm : Conversion of step-wells into draw-wells and health education of communities in areas where the disease is concentrated and persisting, shall be undertaken.

DRD TARGETS FOR THE COVERAGE OF VILLAGES DURING 1987-88

Tables 1 and 2 show targets(1987-88) for "Problem Villages" and coverage of villages.

Table 1 : Sub-Mission Target of Problem Village Coverage in 1987-88

State/UT	Eradication of Guinea Worm	Control of Fluorosis	Control of Excess Iron	Control of Brackishness
Andhra Pradesh	100	845	172	240
Assam			192	
Bihar		100		
Gujarat	100	250		230
Haryana		360		180
Karnataka	200	300		170
Kerala			28	100
Madhya Pradesh	925	150	146	225
Maharashtra	210	250	160	330
Manipur			30	
Meghalaya			30	
Nagaland			20	
Orissa		200	180	205
Punjab		80		75
Rajasthan	1200	450		308
Tamil Nadu		315	190	35
Tripura			40	
West Bengal		300		293
A & N Islands				35
Arunachal Pradesh			30	
Lakshwadeep				4
Total	2735	3600	1218	2625
No. of States/UT	6	12	12	14

* Figures indicate the number of Sub-Missions as per Annual Action Plan 1987-88.

Table 2 : Target for Coverage of Villages in 1987-88

Sl. No.	State/UT	Target(Provisional)
1.	Andhra Pradesh	5380
2.	Assam	2120
3.	Bihar	3400
4.	Gujarat	1050
5.	Haryana	440
6.	Himachal Pradesh	584
7.	J & K	464
8.	Karnataka	3543
9.	Kerala	1157
10.	Madhya Pradesh	5300
11.	Maharashtra	5000
12.	Manipur	213
13.	Meghalaya	600
14.	Nagaland	100
15.	Orissa	4800
16.	Punjab	342
17.	Rajasthan	1600
18.	Sikkim	60
19.	Tamil Nadu	1760
20.	Tripura	700
21.	Uttar Pradesh	9700
22.	West Bengal	1807
23.	A & N Islands	
24.	Arunachal Pradesh	300
25.	Chandigarh	
26.	Dadra & Nagar Haveli	
27.	Delhi	
28.	Goa, Daman & Diu	20
29.	Lakshwadeep	
30.	Mizoram	105
31.	Pondicherry	25
	TOTAL :	50570

The DRD proposes to cover the remaining problem affected villages during the remaining two years, the targets for which will also be received in similar manner.

MEMORANDUM OF UNDERSTANDING BETWEEN CSIR AND DRD

Recently, CSIR has finalised the Memorandum of Understanding (MOU), between CSIR and DRD, related to Technology Mission, in which the participation of CSIR through its four identified R & D Institutions together with the other institutes and the CSIR network of PTCs has been identified in selected Mini-Missions and Sub-Missions. The MOU takes into consideration the following specific activities and the participating Institutes.

- Scientific source finding, conservation and recharging of water sources
- Water quality evaluation of existing sources and new sources
- Improvement of traditional methods for water collection and storage
- Treatment of water
- Improvement of materials and designs
- Improvement of maintenance methods
- Technology transfer and training

In keeping with these requirements on the part of NEERI and with constant dialogue with the State Implementing Agencies, NEERI has contributed in providing technologies back-up to the Mission in the following ways.

NEERI'S ROLE IN THE WATER TECHNOLOGY MISSION

The role of NEERI is to provide technological back-up in solving the problems of drinking water with excessive fluorides, iron and biological contamination. To solve these problems, NEERI has made six distinct groups under which the activities are in progress and these are :

* Defluoridation
* Iron removal
* Slow sand filtration
* Eradication of guinea worm
* Disinfection of open draw-wells
* Treatment of water with multiple water quality problems

It is most essential to integrate the training needs in transfering technologies and NEERI has identified the training needs commensurate with the requirements of the Mission in three categories :

* **Training** : organising oriented courses for the identified groups of implementing agencies on the technologies to be contributed by NEERI
* Providing faculty on request by the State Agency and Mission Directorate
* Compile information and presentation of Mission identified technologies in various meetings, conferences, seminars, symposia, workshops, etc.

The need to undertake R & D activities in the topic of interest with relevance to the Mission objective is an essential component of the integrated approach in solving the drinking water problems. Some of the R&D topics identified at this stage are as follows :

i) Development of bioassay test to evaluate efficacy of abate and chlorination in the eradication of guinea worm through control of cyclops

ii) Development of chemical treatment of water for guinea worm control

iii) Development of portable kit for water quality assessment

iv) Development of iron removal units

v) Development of split defluoridation

vi) Development of multiple treatment technology package unit using dissolved air floatation techniques

vii) Water management for small communities with reference to water quality control

PROGRESS BY NEERI

i) **Water Quality Assessment** : Water Quality Assessment from a representative sample village covering all the talukas of the following districts has been completed.

Kurnool (A.P), Ramnathapuram (T.N.), Jhabua (M.P.), Gurgaon (Haryana). Gulbarga (Karnataka), Bankura (West Bengal) and West Khasi Hills (Meghalaya).

The Water Quality Assessment documents were made available to the concerned.

ii) **Water Technology Laboratory** : Detailed designs for the establishment of Water Technology Laboratory including specification of fittings, equipment, glassware, chemicals, methods of testing and related information are prepared.

iii) **Treatability Studies** : To establish the appropriate technology for specific cases, treatability studies have been carried out at Uletha and Fazilpur (Haryana), Tartur (Andhra Pradesh), and Nanaliliya, Khara and Ingorala (Gujarat) on defluoridation and at Jagdeeshpur, Raigarh and Dadra (Uttar Pradesh) and Agartala and Udaipur (Tripura) on iron removal. Based on the treatability studies, designs have been finalised.

iv) **Preparation of Technology Information Packages (TIPs) :** The Institute has prepared Technology Information Packages (TIPs) on Defluoridation, Iron Removal, Slow Sand Filtration, Improved Muscle Power Water Treatment Plant, and Training Course Manual for specific chemical and bacterial parameters.

The TIPs cover basic process, theory, unit operation and unit process, design criteria and field designs. The TIPs assist the engineers to transfer the technology into field use.

v) **Fabrication/Drawings on Defluoridation and Iron Removal :** The design and drawings both for Defluoridation and Iron Removal units have been completed for the following places:

Defluoridation

Uletha (Haryana)	:	40 m^3/hr
Fazilpur (Haryana)	:	80 m^3/d
Tartur (Andhra Pradesh)	:	20 m^3/d
Nanaliliya (Gujarat)	:	50 m^3/d
Ingorala (Gujarat)	:	50 m^3/d
Khara (Gujarat)	:	50 m^3/d

Iron Removal

Rabindra Bhavan (Tripura)	:	1 m^3/hr
GB Hospital (Tripura)	:	1 m^3/hr
Udaipur (Tripura)	:	0.2 m^3/hr

vi) **Field Camps** : National Defluoridation Camp was held at Amreli, Gujarat during 20-25 April, 1987. Nearly forty persons from all over the country participated in the camp in fluoride affected villages in the Amreli District and specific demonstrations were given in each of these villages covering an estimated population of 90,000. Over 1000 from the surrounding villages participated in the domonstration at Amreli.

National Iron Removal Camp at Agartala, Tripura, was held during 14-18 July, 1987. Samples were collected for water quality evaluation and identification of iron problem villages. Nearly 40 participants took part in the Camp. Iron removal plants were installed at Rabindra Bhavan and GB Hospital, Agartala, Participants completed a home design exercise on iron removal. The technology was also demonstrated in and around Udaipur. The Domestic Iron Removal technology was explained and demonstrated to the villagers. The domestic treatment was acclaimed by all the participants.

vii) **Development of Portable Kits for Water Quality Assessment :**

* Iron - A kit has been assembled, tested and given to a local entrepreneur.
* Residual Chlorine - A kit using syringaldazine reagent is standardised and a proto-type will be available for test in the field.
* Comparator for iron estimation : A handy comparator for iron estimation has been fabricated and is being tested.
* Colorimetric/Spectrophotometric Kit : A prototype unit for fluorides, iron and other colorimetric tests required under Water Technology Mission has been assembled.
* Rapid bacteriological examination of potable water : The work is in progress and an assembly will be available by March 1988.

viii) **Audio-Visual Aids :**

NEERI has prepared the following video cassettes :

* Bacteriological Examination of Water
* Defluoridation Camp at Amreli
* Iron Removal Camp at Agartala
* Defluoridation-Nalgonda Technique

ix) **Training Programmes :** In partial fulfilment of the demands for Water Technology Mission implementation, NEERI will undertake the following training programmes, for the identified staff groups of implementing agencies, on the technologies to be contributed by NEERI.

a) Water Analysis

1) Comprehensive Training Programme (15 days duration)
   * 8-26 February, 1988 (s/t adequate response : 25 participants)

2) Short-term Training Programme (5 days duration) :
   * 9-13 November, 1987

The five day duration training covers limited physico-chemical, and bacteriological parameters (pH; Conductivity; turbidity; alkalinity; hardness; chlorides; fluorides; nitrates; sulphates; iron; manganese; etc.) and essential practical work and demonstration

b) Technology Awareness

1) Defluoridation : One day duration. Fifty participants each batch
   * 18th November, 1987
   * 13th January , 1988
   * 16th March, 1988

2) Iron Removal : Half day duration. Fifty participants each batch

* 19th November, 1987
* 14th January, 1988
* 17th March, 1988

3) Slow Sand Filtration : Half-day duration. Fifty participants each batch

* 19th November, 1987
* 14th January, 1988
* 17th March, 1988

The awareness programmes are in series so that the participants can avail one or more in a row.

Work Proposed under Water Technology Mission

* Water Quality Analysis : Satara & Latur Districts of Maharashtra State
* Camp : Bateriological Analysis of Water in November - 1987 (Eastern Region)
* Development of Mobile Water Quality Testing Laboratory
* Water Management (Eastern Islands)
* TIPs on Disinfection and Guinea Worm Eradication
* Installation of Defluoridation/Iron Removal Plants at identified places
* Audio-Visual on Chemical Analysis of Potable Water
* Improved versions of field analysis kits for Physico-Chemical and Bacteriological Examination of Water
* Evaluation of field installation and the portable Kits.

INAUGURAL ADDRESS

Md. Inamul Haq

Chief Engineer, Panchayat Raj, Hyderabad

Mr. President and distinguished colleagues! I am thankful to Prof. Khanna, Director NEERI for having given me the opportunity to inaugurate the Proceedings of this Meeting.

As you know NEERI is contributing the technologies in the fields of Defluoridation, Iron removal, Slow sand filtration and Laboratory development, etc. The gesture of the NEERI in inviting all of us to meet as forum to be enlightened on these technologies, with special reference to quality treatment of drinking water for rural masses, is first of its kind. Till now at various seminars and workshops, various technologies have been discussed at length at National and Regional levels without much reference to their field applications. I hope that the present deliberations will be more useful for the meaningful transfer of the technology to the field.

The advent of the Technology Mission on Drinking Water in Villages and Related Water Management has brought a radical change in the approach towards solving the drinking water problem in rural sector. It will also fulfill the objective of United Nations declaration that "all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs."

Our main sources of drinking water supply are either surface water or ground water, subject to certain quality parameters which would be either acceptable or should be the cause for rejection. It is here that the NEERI as a National Institute is playing an important role.

If I am not wrong, it can be said, in determining the quality parameters, one has to keep in mind that "all things are poisonous, nothing is not a poison. Only the dose determines whether a thing has poisonous effect or not. (T.V. Hohenheim)"

The later modifications brought about in the concept of Technology Mission by introducing Sub-Missions for specific health hazards such as guinea Worm, Fluorosis, presence of excess salinity and excess Iron have increased the responsibility for all the participating agencies in implementation of Technology Mission Programme.

So far, no exhaustive systematic analysis has been carried out for identification of villages which are having excess fluorides, salinity and iron as has been for the presence of guinea worm in water sources. This should be ensured by formulation of Task Force at National level on the same lines as with guinea worm prevalence for each Sub-Mission.

At this juncture, I want to draw the attention of this Gathering about certain issues in connection with application of various technologies. Our experience with the pilot desalination plants that are set up at Penumarru, Kattuvapalli and Zelladupadu shows that the successful transfer of any technology to the rural areas, requires users acceptance than imposition of the same upon the community. As such, utmost care shall be taken before any technology is adopted.

Once the plants are set up, their operation and maintenance plays an important role in the technology being accepted by the community. The quality of operation and maintenance shall not slide down, which ultimately may result in the rejection of the technology itself by the people.

The personnel who would be in charge of these plants be imparted training in advance, in operation and maintenance. Selection of local youth for this purpose will further reinforce our efforts.

Besides operation and maintenance, periodical monitoring and evaluation of the system is inevitable and shall continue even after completion of the Mission's Programme for fruitful use of the assets created by the Mission.

The introduction of latest technologies shall not result in neglecting existing systems/assets of water supply, and should be continued as a parallel system since the supplies from the plants will be limited to drinking and culinary requirements only.

Keeping in view the above constraints, if we evolve solutions on cost-effective measure, I hope there will be very limited chance of any sag to develop in adopting the technologies under various sub-Missions.

In adopting a technology, one can not universalise the approach, as the problems are situation and location specific. Quality parameter-wise also it may differ from place to place, as the tolerance of human beings to various chemicals varies with climate, exertion and habits with regard to personal hygiene, food and environmental conditions.

Before I conclude, I would like to mention that :

1. There is need for very well thought out schedule to educate and create awareness among the field staff to discard hesitation to adopt these technologies, and to be fair about them.

2. A look at the extent of acceptance and application of various research made, let it be either by CBRI, CRRI and NEERI, etc., reveals that very little effort is made in this field due to lack of codification. It is high time that a beginning is made in this direction.

3. As per department procedure, all materials including machinery and equipment are to be purchased from approved firms having ISI certification. This is to have quality product and to facilitate quality

inspection based on standards fixed by ISI. At present, there is no such procedure. This has to be done on priority along with costing.

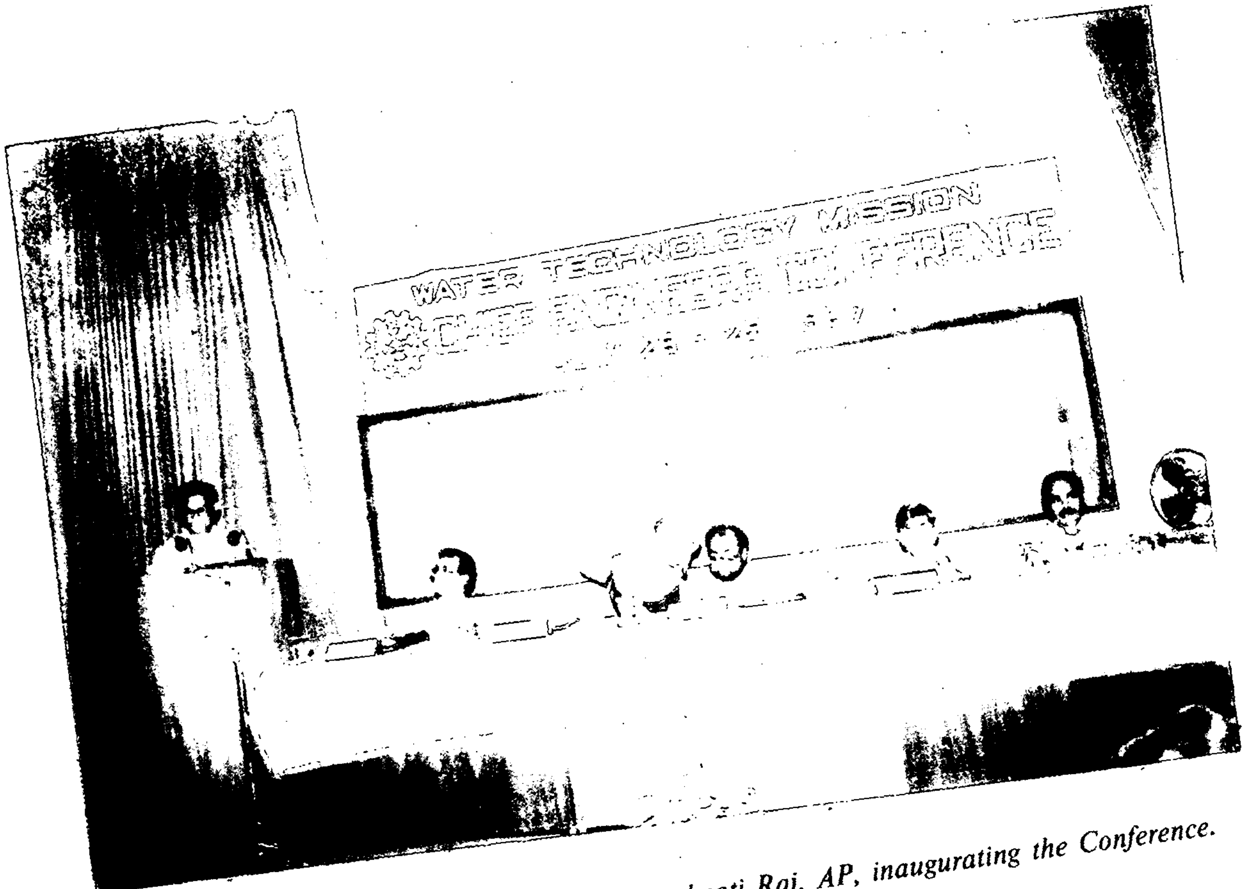
4. Problem quantification has not yet taken shape. There is need for setting up of a fully equipped cell for this purpose attached to PHED.

Let us not be paralysed by the magnitude of the work ahead of us and by the resources needed to reach the goal we have set ourselves : Water and sanitation for all.

I hope that our efforts in finding out cost effective technology mix solution will bridge the gap in resources to a considerable extent.

Let us deliberate and find out effective solutions without any prejudice either towards the technology developing agency or the implementing agency or towards the technology itself vis-a-vis conventional systems and approach.

Thank you.



Mr. Md. Inamul Haq, Chief Engineer, Panchyati Raj, AP, inaugurating the Conference.

Mr. Gauri Ghosh, Mission Director and Joint Secretary, Ministry of Agriculture, Govt. of India, delivering the Keynote Address.

KEY-NOTE ADDRESS

STRATEGIES FOR IMPLEMENTATION OF WATER TECHNOLOGY MISSION

G. Ghosh,
Joint Secretary
Department of Rural Development
Government of India

Prof. Khanna, Mr. Bulusu and distinguished Delegates

It gives me immense pleasure to deliver the Key-Note Address on Strategies for Implementation of Water Technology Mission. I must thank Dr. Khanna as well as Mr. Bulusu for giving me this opportunity to interact with you, clarify some of the grey areas and speeding up the implementation of Technology Mission. This is particularly important in the context that the first Chief Engineers' Conference on Water Technology Mission is being held under the auspices of National Environmental Engineering Research Institute - an organisation entirely devoted to the need of development of appropriate technology for supply of safe drinking water to the rural masses.

Long before the introduction of the Technology Mission, the Public Health Engineering Departments (PHEDs) as well as NEERI were in existence. The technologies which we are going to discuss to today and tomorrow were all developed or were under various experimental and developmental stages by NEERI. The question comes why we are here and what is the Technology Mission and what are its strategies.

Five National Societal Missions have been launched by the Hon'ble Prime Minister last year. They are Drinking Water, Oilseeds, Immunisation, Illiteracy Removal and Communications. The question was that in spite of 40 years of Independence and progress made in various areas of science and technology, why we could not change the life of an ordinary man in a village. In spite of spending a large amount of money, why we could not provide a sustained water supply to the rural areas? Why a large number of children every year dies of water-borne diseases? Why in spite of providing safe drinking water in a village, people still drink water infected with guinea worm or with other bacteriological contamination. The Drinking Water Technology Mission is an attempt to bring the scientists, research workers, academicians, practising public health engineers, consultants, administrators, political leaders, journalists, sociologists and environmentalists all in a single forum to achieve the goal of safe drinking water for all.

One of the areas I would like to emphasise today is project preparation. It is a fact that projects were being prepared in a systematic fashion under various bilateral or World Bank or UNICEF schemes. The moment there is a rider of preparation of projects with supporting staff like adequate number of geohydrologists for source finding, sociologists for public awareness, technical personnel for training, the projects got implemented in perfect fashion. But, this systematic approach constitutes a small amount of the total expenditure. In the large context of expenditure, it is always a slip-shod approach without a prior survey for source, without involvement of proper technical personnel and above all without a follow-up evaluation and monitoring. It would be shocking to know that even proper water quality monitoring has not been done after a system is completed. The basic approach of Technology Mission is to prepare systematic projects and implement them scientifically and above all in most cost-effective fashion.

We have Rs.7,700 crores to cover the villages in the Seventh Plan. Our target is the 2.27 lakh identified problem villages. Average per capita expenditure comes to be approximately Rs.275 against which we have approximately Rs.140 per capita to implement these projects. This means we have to do the job of Re.1 with 50 paise. The projects which we are receiving under ARWSP are widely varying between 80-90 rupees per capita to as high as to 3,500 rupees per capita. I am not prepared to believe that there is no scope for reduction in this cost per capita. However, in our Public Health Engineering Departments there is no conscious attempt to systematise the drilling operations, systematise project monitoring, systematise project implemetation and above all control the influx of personnel. Due to improper planning and indiscriminate sanctioning of the schemes and their late implementation creating inflation in thier cost, we some time pay as high as 100% of the original cost, over and above the estimated cost.

In the Technology Mission, our main strategies are to focus on 50 Mini-Mission areas and to involve the new cost-effective S & T techniques in them and their replication in all programmes. Along with these are five Sub-Missions. The first one is the most important, on Source Finding, Water Quality and Quantity Monitoring and Conservation of Water; the second one is on Eradication of guinea worm; the third one is on Control of Fluorosis; the fourth one is on Control of Brackishness and the fifth one is on Removal of Excess Iron. We have asked each and every State to furnish village-wise information based on the original 2.27 lakh problem villages and on the villages which are having the incidence of the problems mentioned just now under the various Sub-Missions. I am sorry to say that, excepting a few, nobody could submit the information. I am not prepared to believe that the experienced and well-qualified Chief Engineers are not in a position to prepare the simple basic documents which will help us to prepare the detailed project report. Is it then the mere lethargy, or lack of understanding, or lack of sense of priority? Village water supply is not possible unless the village-wise project preparation is done. We find that we are playing with only numbers, the moment the detialed information is asked village-wise, we draw a total blank. If Rs.800 crores worth of projects are being implemented every year without this basic information, it shows that a large amount of public money is being squandered. You may answer the question as to who is responsible for it. I would urge upon you to collect information which may be a bitter truth but let it be projected. Let the projects be prepared on fundamental basic information. Unless we move fast, it is the poor rural people who would suffer and the trust reposed in us by the Nation and the Prime Minister will not be fulfilled.

Besides the proper project preparation, it is necessary to build a strong team of Geologists and Geohydrologists in every Public Health Engineering Department. They should be trained under the regular training programmes of Central Ground Water Board and NGRI. Required number of laboratories for water quality testing also need to be set up. These need not be a costly affair but simple laboratories only. We have asked the States to project small water testing kits developed by Defence Laboratory, Jodhpur, but unfortunately actions have not yet started. By October, each State should cover at least 150 villages for awareness compaign for safe drinking water.

NEERI had developed the iron removal plants as well as defluoridation plants long back. They can be fabricated locally which will provide employment opportunities to rural people and can be replicated without much effort in alarge number. Instead of waiting for somebody to come to your State and do the work for you, the Chief Engineers should find out from others how these plants are working and how they are being implemented and get them fabricated locally or constructed by local masons and start operating them. The cost of the plants is very low. This will enable you to fulfill the targets given to you by the Mission Directorate.

NEERI has conducted a Fluorosis Camp at Amreli and National Iron Removal Camp at Tripura. You should take advantage of such training programmes whenever they are announced. I would also suggest that you should have continuous interaction with NEERI, other CSIR laboratories as well as other State Governments who are tackling similar problems.

With little innovations, these projects can be implemented very fast under ARWSP, Technology Mission and MNP programmes. If a village has been declared as covered but still has a problem of fluorosis or brackishness or excess iron, these can still be tackled under the Sub-Missions.

Above all, we have to move in a big way for the awareness campaign and preferably involving voluntary agencies. They can be of help in replication, in construction of iron removal, defluoridation plant, etc., in villages. CAPART should be able to provide them with finance. I would also request you to debureaucratise the implementation of programmes. People should be kept in confidence, involved from the implementation of strategy to maintenance and have further evaluation. A massive awareness campaign should be launched. It does not cost large amount of money but demands involvement and sincerity. The awareness campaign launched at Jhabua district in Madhya Pradesh is an ideal example. I would request all the Engineers to involve the voluntary agencies in their States or non-governmental organisations to pick up this job. Without public awareness for drinking of safe water and raising their interest to safeguard the sources, the strategy would not be successful. Proper media campaign will be of great use in creation of the awareness. You may take the cassettes prepared by NEERI and organise awareness programme even among the Engineers first and then the villagers.

Supply of drinking water is not an isolated subject. You have to deeply interact with Minor Irrigation, Forest, Soil Conservation, Agriculture, Dry Land Farming, Rural Development Department works like RLEGP, NREP and above all with Health, Education and Environment Departments. The Technology Mission is an integration of all disciplines to achieve the common goal. I will request you to make full use of various Committees and try to dovetail the resources available within your State itself. You will be surprised to find how rich they are. For this, you have to possibly start with certain group discussions or one-day workshops among the various disciplines st the state headquarters immediately. The recent regional seminar at Gandhigram, Madurai has been a success. But we would like to have your Action Plans. We have discussed enough, now what we require is the specific action plan in a time framework. I hope this Workshop would not end with endless talk on the technologies only but shall prepare specific action plans for various States with clear cut responsibilities before we disperse.

I must thank Prof. Khanna again for giving me this opportunity. Hope there will be a two way interaction in this Conference where we all would learn a lot from the rich field experience from you.

Thank you.

SLOW SAND FILTRATION

R. Paramasivam
NEERI, NAGPUR

INTRODUCTION

Drinking water should be bacteriologically safe, aesthetically acceptable and free from excessive concentration of mineral salts of health significance. Natural waters often do not satisfy all these requirements and therefore need treatment. Slow sand filtration is a simple process for purifying polluted surface waters such as from village ponds, lakes, canals, streams and rivers.

WHY SLOW SAND FILTRATION

Because it has several desirable features. These are :

Simplicity of design, construction, operation and maintenance; often local materials and skills could be readily employed with the advantage of cost reduction.

Efficiency - near total removal of pathogens and viruses, highly efficient in removal of turbidity and organic matter, little wastage of water and low production of waste sludge.

Reliability - Minimum of mechanical and electrical equipment that can go wrong or need replacements and repairs.

Economy - Less energy intensive, no need for expensive chemicals which are difficult to procure, dose and control.

Acceptability - Filtered water less corrosive and more uniform in quality than that of a chemically treated water.

WHEN TO ADOPT SLOW SAND FILTRATION

Purification by slow sand filtration can be adopted when :

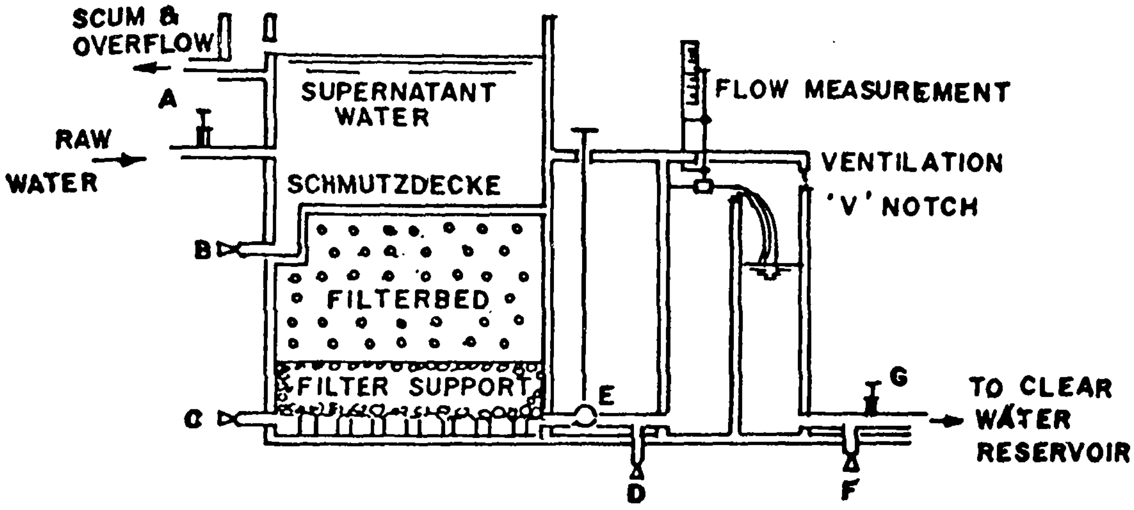
* The raw water turbidity is generally less than 30 NTU and exceeds this limit only occasionally for short periods. (If the suspended solids, especially turbidity of raw water is high, the SSF has to be preceded by a simple pre-treatment unit such as plain sedimentation tank/roughing filter/infiltration gallery, etc., to reduce the turbidity to a level acceptable by SSF).
* Land, labour and filter sand are readily available and at low cost.
* Chemicals and equipment are difficult to procure.
* Skilled personnel for operation and maintenance are not locally available.

BASIC ELEMENTS OF A SLOW SAND FILTER (Fig.1)

- An open box about 3.0 m deep, rectangular or circular in shape and made of concrete, masonry or ferro-cement.
- Supernantant water layer, usually 1.0 m deep. Provides the driving force for water to flow through the filter and to overcome frictional resistance.

  Allows improvement in water quality due to sedimentation, natural flocculation, removal of biodegradable organic material and die-off of bacteria.

- Bed of filter sand usually 80-100 cm initial depth. Provides a framework for biological organisms to develop, multiply and to bring about purification; also serves as a strainer for large suspended particles.
- Supporting gravel layers and underdrainage system supports the filter medium, prevents it from entering and blocking the underdrains and provides a free passage for filtered water.



A - RAW WATER INLET VALVE

B - SUPERNATANT DRAINOUT VALVE

C - RECHARGE VALVE

D - FILTER SCOUR VALVE

E - FILTERED WATER OUTLET VALVE

F - FILTER TO WASTE VALVE

G - FILTERED WATER VALVE

FIG.1
BASIC ELEMENTS OF A SLOW SAND FILTER (SCHEMATIC)

MECHANISM OF PURIFICATION IN SLOW SAND FILTER

Slow sand filtration is a combination of physical, chemical and biological processes. The phenomena which occur in and above the filter bed are quite complex. These are briefly described below :

Straining : Retention of particles which are too large to pass through the pores of the filter sand grains.

Sedimentation : The surface area of sand grains per unit volume is so large, that a slow sand filter acts as an extremely effective sedimentation unit.

Adsorption : Due to a combination of diffusion, mass and electrostatic attraction and other mechanism even colloidal impurities adhere to the surface of the sand grains.

Chemical and biological activities : These play a major role in the purification processes which occur on and within the filter bed.

The presence of sufficient oxygen in water to be treated is essential. Biological oxidation of organic matter in an aerobic environment contributes to high performance of slow sand filters.

Algae play an important role. In the presence of sunlight, these are able to build up cell material from simple minerals such as water, carbon dioxide, nitrates and phosphates, and in the process, produce oxygen which in turn facilitates biodegradation of organic matter.

Although most of the bio-chemical purification occurs in the so called "Schmutzdecke" (the top 10-20 mm of the filter bed), biological activities in the lower part of the filter bed (40-50 cm) may be considerable.

EXPECTED PERFORMANCE OF A SLOW SAND FILTER

Quality Parameter	Degree of Purification
Natural colour	30-100% removal
Turbidity	To less than 1 NTU
E. coli	95-100% reduction
Cercariae	Virtually complete removal of schistosoma cysts and ova
Viruses	Virtually complete removal
Organic matter (COD)	60-75% reduction
Fe & Mn	Largely removed
Heavy metals	30-90% reduction

PLANT LAYOUT

Local topography, placement of pump-house and other facilities and possible future expansion influence the plant layout.

Wherever topography permits, gravity flow of raw water to the plant should be preferred, even if laying of additional pipe line is required. This will cut down recurring energy costs and facilitate easy operation and maintenance of the plant.

The layout of the treatment plant should be compact enough to facilitate effective day-to-day operation and maintenance of the plant.

Filters may be circular or rectangular in shape. Circular filters are not economical except for small installations. Rectangular filters facilitate common wall construction, easy operation and maintenance.

CONSTRUCTION ASPECTS

The costruction of slow sand filters should be based on sound engineering principles. The structural design, the construction methods and materials are governed by local conditions.

Aspects that need careful consideration are : (i) the type of soil and its bearing capacity; (ii) the ground water table and its fluctuation and (iii) the availability and cost of construction materials and labour.

Filters may be constructed of reinforced concrete, masonry, brick-work or ferrocement, or an excavated structure with protected sloping walls. Filters with protected sloping walls are usually rectangular in shape.

Water-tight construction of the filter box should be guaranteed, especially when the ground water table is high.

The top of the filter should be at least 0.5 m above the ground level in order to keep away dust, children and animals.

The danger of short-circuiting of raw water along the walls may be prevented by roughening the inner surface of side walls from bottom up to the sand bed level.

The inlet structure should be so designed and constructed as to cause minimum disturbance to the sand bed by incoming raw water.

The outlet structure usually incorporates a means for measuring the filter flow and for backfilling with clean water after the filter has been scraped. The crest of the outlet weir should be located at or slightly above the top of the sand bed to avoid occurrence of negative head in the filter bed.

A supernatant drain-out chamber with its top just above the sand level should be provided to facilitate drainout of supernatant in short time.

An overflow pipe/weir should be provided to facilitate drainage of surplus water entering the filter and floating scum.

ECONOMIC AND COST ASPECTS

The cost of a filter excluding pipes and valves is made up of two components; the total cost for floor, underdrains, sand and gravel; and the cost of walls of the filter box.

This cost in general is :

$$C = K_A A + K_P P$$

where A is the total filter bed area in m^2; P the total wall length in m, K_A the cost per unit area of filter bed and K_P the cost per unit length of wall.

For rectangular filters arranged in a row with common walls, the condition for minimum filter cost is

$$L = [\ 2\ A/(n+1)\ ]^{1/2}$$

and $b = (n+1)L/2n$

where n is the number of filters, b is the breadth and L is the filter length.

CAPITAL COST

The general expression for the minimum cost is :

$$C = K_A A + 2K_P\ [2A(n+1)]^{1/2}$$

A general cost model (Nagpur 1986 prices) for filter bed works out to :

$$C = 2000\ A^{0.869}$$

(A in m^2)

Detailed cost analysis indicates that SSF are cost-effective for plant capacities up to 8 mld in comparison to conventional rapid gravity filters.

TREATMENT COST

The cost of treatment by SSF ranges from 0.5 to 1 Re/m^3.

STARTING UP A NEW FILTER

While commissioning, a newly constructed filter is charged with water from bottom through the outlet chamber till the water level rises 10-15 cm above the sand bed. The ensures expulsion of entrapped air in the filter bed and the underdrain. The filter is then filled with raw water from top to the normal working level (NWL) by opening the inlet valve. Initially the rate of filling should be low to prevent scouring of sand around the inlet. The filter is put into operation by opening the outlet valve and gradually increasing the rate to the design value over a period of 4 to 6 hours. The filter is run continuously to allow the active biological film to be formed and get established on the sand bed. This initial ripening or matuaration of the filter may take 3-5 weeks. Till then, the filtrate is run to waste or put into supply only after adequate chlorination. The ending of the ripening period is determined by the bacteriological quality of filtered water which should meet the prescribed specification.

ROUTINE OPERATION

For best results, a mature filter should run continuously at the design filtration rate. The rate control is achieved either at the inlet or at the outlet of the filter.

In an inlet-controlled filter, the filtration rate is set at the inlet weir chamber by regulating the inlet valve. Frequent manipulation of the valve is rarely required. At first, the water level over the filter will be low, but gradually it will rise to compensate for the increasing resistance of the filter bed. Once the level has reached the overflow outlet, the filter has to be taken out for cleaning.

Inlet rate control minimises the routine work of the operator. The rate of filtration will be nearly constant with this method and the build-up of resistance in the filter is directly visible. On the other hand, the influent water is not retained for long at the beginning of the filter run, which may reduce the efficiency of treatment.

In an outlet-controlled filter, which is more common, the rate of filtration is set with the outlet valve. Daily or every alternate day, this valve has to be opened a bit to compensate for the increase in resistance in the filter. The disadvantage of this method is that the outlet value has to be manipulated on a regular basis. The operator has to visit the plant at least every day, otherwise, the output will fall. The water is retained for five to ten times as long as in the inlet-controlled filter at the beginning of the filter-run, which may make purification more efficient. Removal of scum will also be much simpler than with inlet-controlled filtration. In many situations, electricity and diesel fuel are not available all the time, so existing SSF plants, some times, function only for part of the day. In such cases, either a raw water storage reservoir, which can feed water to the filters under gravity supply, should be built, or 'declining rate filtration' should be used to ensure satisfactory filtrate quality. That is, when the raw water pumping is stopped, all valves remain in the same position and filtration continues at declining rate as the water level in the filter falls. When the raw water supply is restored, the water standing over the sand bed will rise to its earlier level. Where declining rate filtration is used, a larger filter area is needed.

FILTER CLEANING

When the filter has attained the maximum permissible headloss, it is taken out of service for cleaning. The inlet is closed and the supernatant is drained out or allowed to filter through so as to expose the sand bed. The water level is lowered 10-15 cm below the top of the sand bed by opening the scour valve. Without allowing the bed to dry up, the filter is cleaned manually by removing the top 2-3 cm layer of sand along with the filter skin. The filter is returned to service by admitting through bottom filtered water from the adjacent filter to a level a few centimeters above from top. The removed sand is washed, dried and stored for future use.

RESANDING

Due to periodic cleaning, when the sand depth is reduced to a minimum of 30-40 cm, it is necessary to make up the sand depth to the original level. This is done by replenishing with a fresh lot of sand taking care to see that the remaining old sand is placed on top of the new sand. This avoids accumulation of dirt in the deeper layers of filter bed and helps in quick ripening after resanding.

DAILY OPERATION ROUTINE

Activity	Procedure
1. Regulation of supernatant	Manipulate inlet valve (A) to maintain a constant supernatant water level and to avoid overflow
2. Removal of scum and floating matter	Allow temporarily the supernatant with the scum to overflow or manually remove using long handled wire net
3. Checking the filtration rate	Observe flow indicator and note the rate
4. Regulation of filtration rate	Manipulate filter outlet valve(E) to maintain desired constant rate
5. Shutting-off the filter	Cleaning is necessary when the filter outlet valve(E) is fully opened but desired rate is not achieved

[redacted]

SCHEDULE OF ACTIVITIES FOR CARETAKER

Daily

* Check the raw water intake (some intakes may be visited less frequently)
* Visit the slow sand filters
  - check and adjust the rate of filtration
  - check water level in the filter
  - check level in the clear water well
  - sample and check water quality
* Check all pumps
* Maintain the logbook of the plant

Weekly

* Check and grease all pumps and moving parts
* Check the stock of fuel and order, if needed
* Check distribution network and taps and arrange repairs, if necessary
* Communicate with the user public for problems, if any,in water supply
* Keep the plant-site clean

Monthly or less frequently

o Scrape the filter beds (s) as and when necessary

o Wash the scrapings, dry and store the washed sand

Yearly or less frequently

o Clean and disinfect the clear water well

o Check the filter and the clear well for water-tightness

Every two years or less frequent

o Resand filter unit(s) as may be necessary

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DISCUSSION

Mr. R.E. Sinha, (Koraput, Orissa)

Q. What are the conditions for adopting slow sand filter plant as treatment unit for removal of iron? What will be range of iron concentration in raw water which can be applied to slow sand filters for effective functioning ?

A. In general, slow sand filters are adopted for treatment of surface waters which are usually polluted and do not present a problem due to presence of iron. However, iron in concentration encountered in natural surface waters will be completely removed in a slow sand filter. When applied for treatment of iron-bearing ground waters, the filters have to be preceded by oxidation of iron either by aeration or chemical addition and sedimentation.

Mr. M.M. Datta, (New Delhi)

Q. Will the author throw light on effect (quality) of pretreatment by Alum(floc) to take care of high turbidity for a short period of time?

A. As a rule, alum coagulation and sedimentation preceding slow sand filtration is not recommended because it makes the treatment process quite complex, especially in rural situations. High turbidity (up to 100 NTU) could, however, be treated only if it is of a temporary nature for a few days.

Mr. G. Ghosh, (New Delhi)

Q. Please give some details of cost, specially maintenance costs. Whether TRYSEM training can be organised for masons to build them? What about training voluntary organizations in building such plants?

A. The cost of maintenance of slow sand filters is quite low and consists of periodic cleaning of the filter by manually removing the top layer (2-3 cm) of sand, washing it and storing after drying for reuse. The cost of water treatment by slow sand filtration ranges from 50-100 paise/m^3.

TRYSEM and voluntary organisations can be involved in training of masons for construction of slow sand filters under proper supervision. Brick or stone masonry structures are more readily amenable for construction of slow sand filter under such programmes.

Mr. M. Inamul Haq., (Hyderabad)

Q. It is becoming quite difficult to secure sand of required quality (U.C., 2-3) in rural areas. The wastage is roughly 80% and cost increases by 10 to 15 per cent. Is there any possibility of replacing the filter media characteristics without affecting the filters?

A. A careful physical examination of the prospective sources of sand supplemented with laboratory testing will go a long way in minimising the labour for screening and wastage of sand so as to keep the cost of sand low.

Q. Turbidity excess. Between increases in size of the tank and introduction of chemically aided sedimentation process, which would you advocate ?

A. When extended storage is not effective in producing a settled water of desired turbidity, chemically aided sedimentation could be an alternative if resorted to in the first of the series of the storage tanks.

Mr. R.S. Nema, (Shahdol)

Q. In Shahdol district, (M.P.), some villages are located on the banks of river Son which carries effluent from mainly Orient Paper Mills. The BOD in the river is less that 20 mg/L (the colour in water is due to lignin). Can the slow sand filter be used for such raw water with suitable economical amendments in the design ?

A. Surface water with a BOD of more than about 5.0 mg/L is not amenable for treatment by slow sand filters. If colour in raw water is of natural origin, an average reduction of about 30% can be achieved by slow sand filtration. Colour of industrial origin is not amenable for treatment by S.S.F.

Mr. R.P. Dubey (Jhabua)

Q. Can the bad odour which is generally felt in the starting of monsoon or rather after the first rains be removed in S.S.F.?

A. If odour is caused due to the presence of readily biodegradable substances, it could be satisfactorily removed by slow sand filters. Post-treatment of filtered water with ammonia and chlorine (chloramination) may be necessary depending upon the nature and cause of odour in the source water.

[redacted]

DEFLUORIDATION

M.V. Nanoti
NEERI, NAGPUR.

INTRODUCTION

Fluoride although beneficial when present in potable waters in concentrations of 0.8 - 1.0 mg/L, has been associated with mottled enamel of the teeth when present in excess of 1.5 mg/L. Skletal fluorosis has been observed at concentrations beyond 3 mg/L. The assessment of dental fluorosis is particularly important in areas where the natural fluoride content of the water supply is high. The most widely used criteria for the assessment is that developed by Dean in 1934. The degree to which teeth are affected are :

Normal, Questionable, Very Mild, Mild, Moderate and Severe : All enamel surfaces are affected and hypoplasia is so marked that the general form of the tooth may be affected. The major diagnostic sign of this classification is the discrete or confluent pitting. Brown stains are widespread and teeth often present a corroded appearance.

DEFLUORIDATION

* It is removal of excess fluorides from water
* Removal is achievable either by fixed bed regenerable media or by precipitation and complexation process
* Recommended defluoridation method - Nalgonda Technique

NALGONDA TECHNIQUE

The technical method for the removal of excessive fluorides at domestic and community levels using precipitation by aluminium salts is popularly known as "Nalgonda Technique". Conditions for accepting

Nalgonda Technique are :

- o Absence of acceptable alternate low fluoride source
- o Dissolved solids are below 1500 mg/L
- o Total hardness is below 250 mg/L
- o Alkalinity of the water is sufficient
- o Raw water fluorides ranging from 2 to 20 mg F/L

BASIC ELEMENTS OF DEFLUORIDATION BY NALGONDA TECHNIQUE

Defluoridation can be achieved using either of the following sequences of Nalgonda Technique.

1) Precipitation, Settling and Filtration
2) Precipitation, Floatation and Filtration

Both these sequences can be used for domestic as well as community water supply.

1. Precipitation, Settling and Filtration

Domestic Treatment : Treatment can be carried out in a container (bucket) of 60 L capacity with a tap 3-5 cm above the bottom of the container for the withdrawal of treated water after precipitation and settling. The raw water taken in the container, is mixed with adequate amount of lime or sodium carbonate, bleaching powder and aluminium sulphate solution, depending upon its alkalinity and fluoride content. Lime or sodium carbonate solution is added first and mixed well with water. Alum solution is then added and the water stirred slowly for 10 minutes and allowed to settle for nearly one hour and is withdrawn. The supernatant which contains permissible amount of fluoride is withdrawn through the tap for consumption. The settled sludge is discarded.

Fill and Draw Type for Small Community : This is also a batch method for communities up to 200 population. The plant comprises of a hopper-bottom cylindrical tank with a depth of 2m equipped with a hand-operated or power driven stirring mechanism. Raw water is pumped or poured into the tank and the required amounts of bleaching powder, lime or sodium carbonate and alum added with stirring. The contents are stirred slowly for ten minutes and allowed to settle for two hours. The defluoridated supernatant water is withdrawn to be supplied through stand-posts and the settled sludge is discarded.

The notable features are :

i) With a pump of adequate capacity, the entire operation is completed in 2-3 hr, and a number of batches of defluoridated water can be obtained in a day;

ii) The accessories needed are few and these are easily available (these include 16 L buckets for dissolving alum, preparation of lime slurry or sodium carbonate solution, bleaching powder and a weighing balance);

iii) The plant can be located in the open with precautions to cover the motor; and

iv) Semi-skilled labour can perform the function independently.

2. Precipitation, Floatation and Filtration :

Domestic treatment is achieved using a 100 L capacity batch type dissolved air floatation cell with hand operated pressure pump. The pump and cell form a compact dissolved air floatation defluoridation system.

Raw water in the cell is mixed with alkali and aluminium salts. A small quantity of air-water mix from the pressure pump is allowed into the cell. The precipitate with fluoride lifts to the top and floats. The treated water collected in a bucket filters through a sand filter. Using this cell, 100 L water is available for use in 20 minutes.

The same principle of floatation is extended to a 500 L capacity dissolved air floatation cell to obtain nearly 1 m^3 treated water per hour for small communities.

MECHANISM OF DEFLUORIDATION BY NALGONDA TECHNIQUE

Nalgonda Technique is a combination of several unit operations and processes incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration to recover water and aluminium salts.

Rapid Mix : Provides thorough mixing of alkali, aluminium salts and bleaching powder with the water. The chemicals are added just when the water enters the system.

Flocculation : Flocculators provide subsequent gentle agitation before entry to the sedimentation tank. The flocculation period permits close contact between the fluoride in water and polyaluminic species formed in the system. The interaction between fluoride and aluminium species attains equilibrium.

- The chemical reactions involving fluorides and aluminium species are complex. It is combination of polyhydroxy aluminium species complexation with fluoride and their adsorption on polymeric alumino hydroxides (floc). Besides fluorides, turbidity, colour, odour, pesticides and organics are also removed. The bacterial load is also reduced significantly. All these are by adsorption on the floc.

- Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so that residual aluminium does not remain in the treated water.

- Simultaneous disinfection is achieved with bleaching powder and also keeps the system free from undesirable biological growths.

Sedimentation : Permits settleable floc loaded with fluorides, turbidity, bacteria, and other impurities to be deposited and thus reduce concentration of suspended solids that must be removed by filters. Sedimentation theory is complex and of little avail, because floc is not uniform and hence its basic sedimentation properties can not be given quantitative values and because the influence of eddy currents can not be predicted. Hence, various factors which influence sedimentation in relation to design and operation depend largely on experience.

Filtration : Rapid gravity sand filters are suggested to receive coagulated and settled water in these filters and unsettled gelatinous floc is retained. Residual fluorides and bacteria are absorbed on the gelatinous floc retained on the filter bed.

Disinfection and Distribution : The filtered water collected in the storage water tank is rechlorinated with bleaching powder and distributed as per adoptable community water supply practice.

RURAL WATER SUPPLY

Rural Water Supply using precipitation, settling and filtration scheme of Nalgonda Technique.

The scheme intends to treat the raw water for villages and includes channel mixer, pebble bed flocculation, sedimentation tank and constant rate sand filters. Designs of entire water facilities for 500, 1000, 2000 and 5000 populations are available. The scheme is gravity operated except the filling of the overhead tank and delivery from treated water sump. Channel mixer is provided for mixing lime slurry or sodium carbonate solution and aluminium salts with the raw water. Pebble bed flocculation is used in place of conventional flocculation in order to avoid the dependence on electrical power supply. The scheme envisages power supply for 2 hr each during morning and evening for filling the overhead tank and for supply of treated water.

After the pumps stop at 8 a.m. the stored raw water from storage tank is fed to treatment plant for next 6 hr. when again the raw water pumping resumes for 2 hr and the cycle is continuous.

The flash mix unit, flocculator, settling tank and filter units operate under gravity system.

The filtered water is stored in "filtered water sump". The supply hours are also assumed to be the same as raw water pumping hours i.e. 2 hr supply each in the morning and the afternoon.

An example has been worked out for a population of 500 to determine the total quantity of water to be supplied :

Rate of water supply	70 Lpcd
Total daily net requirement	70 x 500 = 35000 L = 35 m^3
Total gross requirement (considering clarifier bleed plus filter washings)	35 + 3.5 = 38.5 m^3
Raw water Pumping hours (2 hr each in morning and afternoon)	4 hours (total)

During morning, 50% gross raw water (19.25 m^3) requirement is pumped to raw water storage tank (and balance 50% in the afternoon when power supply resumes). During the period of raw water pumping hours, average rate of raw water going to treatment plant will be 2.406 m^3/hr and the balance quantity is stored.

COST CONSIDERATIONS

The cost estimates for all these facilities are shown in Table 1 and Table 2 and relate to the population equivalents at various water consumption rates in Lpcd for design flow rates. The present design is based on 70 Lpcd in desert areas (40 for human beings and 30 for cattle). Table 3 indicates the capital cost at various flow rates and population equivalents at water consumption rates of 30, 40, 50, 60 and 70 Lpcd.

Table 1 : Cost Estimates For Defluoridation Units (Nalgonda Technique)

Population	Design Flow, (m^3/d)	Capital Cost		O & M (Running Cost)	
		Total Cost (Rs.)	Total Cost (Rs./m^3)	Total cost/day	Total cost (Rs./m^3)
500	38.5	1,22,000	3169	227+(0.0588C+0.22)	5.90+(0.0015C+0.0557)
1000	77.0	1,58,000	2052	295+(0.117C+0.44)	3.83+(0.0015C+0.0057)
2000	154.0	2,10,000	1364	336+(0.235C+0.88)	2.18+(0.0015C+0.0057)
5000	385.0	2,92,000	758	472+(0.5872C+2.2)	1.226+(0.0015C+0.0057)
				$Y_1 = P_1(m_1C_1+A_1)$	$Y_2 = P_2+(m_2C_2+A_2)$

Note : Y = Total O and M cost

P = Energy Cost including depreciation*, interest** and manpower

C = Alum Dose, mg/L

A_1 and A_2 = Cost for bleaching powder

m_1C_1 and m_2C_2 = Cost of alum and lime

* Depreciation = 5% of capital cost

** Interest = 12% per annum

Table 2 : Population served by the Designed Plant at Various Rates of Water Supply (Lpcd)

Design Flow m^3/d	Population to be served at stated Rate of Supply				
	70	60	50	40	30
38.5	500	583	700	875	1166
77.0	1000	1166	1400	1750	2332
154.0	2000	2333	2800	3500	4666
385.0	5000	5833	7000	8750	11666

Table 3 : Capital Cost at Various Flow Rates (m^3/day)

Flow Rate (m^3/d)	Total Cost Rs.	Cost Rs/m^3	Equivalent population at Stated Rates of Water Supply, Lpcd.				
			30	40	50	60	70
30	110000	3550	910	682	545	454	389
40	132000	3000	1212	909	727	606	519
50	138000	2600	1515	1136	909	757	649
60	145000	2300	1818	1364	1091	909	779
70	155000	2150	2121	1591	1273	1060	909
80	167000	1930	2424	1818	1454	1212	1039
100	173000	1700	3030	2273	1818	1515	1299
200	211000	1120	6060	4545	3636	3030	2597
300	260000	900	9091	6818	5454	4545	3896

SLUDGE-WATER AND ALUM RECOVERY :

The sedimentation tanks should be desludged on alternate days for five minutes. The total loss of water in desludging amounts to 1.0 - 1.5% of the total water quantity pumped into the treatment plant. This can be reduced considerably in community plants by making provision for sludge concentration well and drying beds. Water and alum are recovered from the sludge. The recovered alum can be used for purposes other than defluoridation. The fluoride in recovered alum is 8 to 10 gm per kg.

The solids in sludge from sedimentation basins are 0.8 - 1.1% (w/v). By plain sedimentation, the concentration is increased to 2.5 - 3.1% (w/v) in 24 hrs. Subsequent exposure of this concentrate on drying beds increases the solids to 28-30%.

SALIENT FEATURES :

* No regeneration of media
* No handling of caustic acids and alkalis
* Readily available chemicals used in conventional municipal water treatment are required
* Adaptable to domestic use
* Flexible up to several thousands of m^3/d
* Applicable in batch as well as in continuous operation to suit needs
* Simplicity of design, construction, operation and maintenance
* Local skills could be readily employed
* Highly efficient removal of high fluorides, between 2 and 20 mg F/L level to desirable levels.
* Simultaneous removal of colour, odour, turbidity, bacteria and organic contaminants

* Normally, associated alkalinity ensures fluoride removal efficiency
* Sludge generated is convertible to alum for use elsewhere
* Little wastage of water and least disposal problem
* Needs minimum of mechanical and electrical equipment
* No energy except muscle power for domestic treatment
* Economical-annual cost of defluoridation of water at 40 Lpcd works out to Rs.15/- for domestic treatment and Rs.30/- for community treatment based on 5000 population for water with 5 mg F/L and 400 mg/L alkalinity which requires 600 mg/L alum dose
* Provides defluoridated water of uniform acceptable quality

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DISCUSSION

Mr. G. Ghosh, (New Delhi)

Q. You have not spoken about cost of various plants and chemicals.

A. Yes, it is true that I have made very brief mention about the cost aspect. With the time at my disposal, efforts were made to focus on "Nalgonda Technique" and plants designed on the principle.

The details of cost analysis for the plants envisaged to be installed under Technology Mission programme are given in Technology Information Package on 'Defluoridation' published under Mission activities by the Institute.

The capital cost of defluoridation plant capable of supplying treated water at 40 Lpcd to a population of 700 persons is Rs.2,60,000. The domestic defluoridation unit, to be operated manually, is estimated to cost about Rs.300. The annual cost of defluoridation of water at 50 Lpcd worked out as Rs.13.69 and Rs.27.35 for domestic and community treatment respectively, which may come to about 4-9 paise per day per individual, depending upon the raw water fluoride content.

Q. If split defluoridation plant is good for places "where power failure is frequent", how are you recommending a head where you have to pump up water, obviously with the use of energy ? Don't you think that emphasis should be on manually operated and simple plants ?

A. Yes, I also think that emphasis should be on simple plant design. Whether a plant should be selected on domestic or group scale; small community or on township level will depend on requirements, site situation and operational convenience.

Using basic "Nalgonda Technique", NEERI designed various treatment systems, namely Kadiri type, MS Fill-and-Draw, HDPE Fill-and-Draw, Drum Fill-and-Draw, Muscle Power and Split Defluoridation. These are alternatives to enable selection to suit local needs. A community Fill-and-Draw type defluoridation plant with capacity more than 5 m^3/day will need energy as a matter of convenience. The Split Drfluoridation Plant, designed on the basis of split dose of alum, has an advantage of reduced alum dose when fluoride content of water is more than 6.0 mg/L. If this plant is run on electromechanical devices and the power ssupply is not regular, the plant performance will be directly affected, and is likely to result in more than acceptable concentrations of fluoride in treated water. The purpose of defluoridation will hence be defeated. This can be avoided by firstly pumping the water to a head of about 4 m in an elevated tank with capacity to hold water required for about 5 hr plant operation. The design is such that the water head is ultimately utilized for flash mixing, flocculation and sedimentation. The tank may be balanced against ensured acceptable quality defluoridated water.

Mr. B.K. Surana, (Nagaur, Rajasthan)

Q. Please give us an idea of initial cost of Nalgonda Process per litre as well as maintenance and operation cost per litre per head. Is it really economical that conventional method or regional scheme?

A. Please refer to our Technology Information Package on 'Defluoridation' for further details of cost break-up.

Reagarding regional scheme, perhaps meaning thereby, the transporting of water containing acceptable fluorides, the cost factor for economical feasibility can be obtained by computing the cost of defluoridation and cost of transporting the water from given distance. NEERI conducted experiments on defluoridation of water containing 2 - 21 mg/L F and 200 - 1200 mg/L alkalinity. Cost of treatment when compared with the cost of conventional or marginal treatment and pumping can decide choice of regional scheme against defluoridation. For example, defluoridation may be accepted when fluoride content of water is 2.0 mg/L and no other alternate source is available within 7 km. Journal of the Institute of Engineers (Env. Engg. Div.) 60, Pt EN 1, October 1979, may please be referred for more details.

Defluoridation can not be compared with conventional water treatment, because the latter does not remove fluoride. The methods of defluoridation can be compared against each other.

Mr. C.J. Mathews, (Trivandrum)

Q. What is the maximum fluoride content, according to NEERI, in raw water, which can be removed economically and what will be approximate cost then ?

A. We have collected all the possible data for fluoride content up to 20 mg/L and worked out cost analysis for the same. The process feasibility of "Nalgonda Technique" extends to about 30 mg/L Fluoride content of water. This being very rare situation the cost evaluation is not carried out. Normally, the cost of defluoridation of water containing 16 mg/L fluoride and 1070 mg/L as $CaCO_3$ alkalinity, per m^3 compares with transporting water from 50 km. Cases beyond this limit are very rare in our country.

Mr. R.P. Dubey, (Jhabua, Madhya Pradesh)

Q. Is there any small equipment which can be fitted in a hand-pump for defluoridation ?

A. No, there is no such gadget. Fill-and-Draw type Community Defluoridation Plant or domestic treatment is recommended, depending on the requirements.

Mr. Mohd. Inamul Haq, (Hyderabad)

Q. Is there any possibility of developing a system through which the treatment dose (alum + lime) is set up to suit to presence of fluoride without determining the presence of alkalinity ?

A. No, the dose determined in such case will not be factual and process efficiency and economics will be adversely affected. Once the alkalinity of water is analytically estimated, the ready reckoner developed by NEERI though series of jar tests can be used for determining the alum and lime doses.

Mr. M.S. Miglani, (Gurgaon, Haryana)

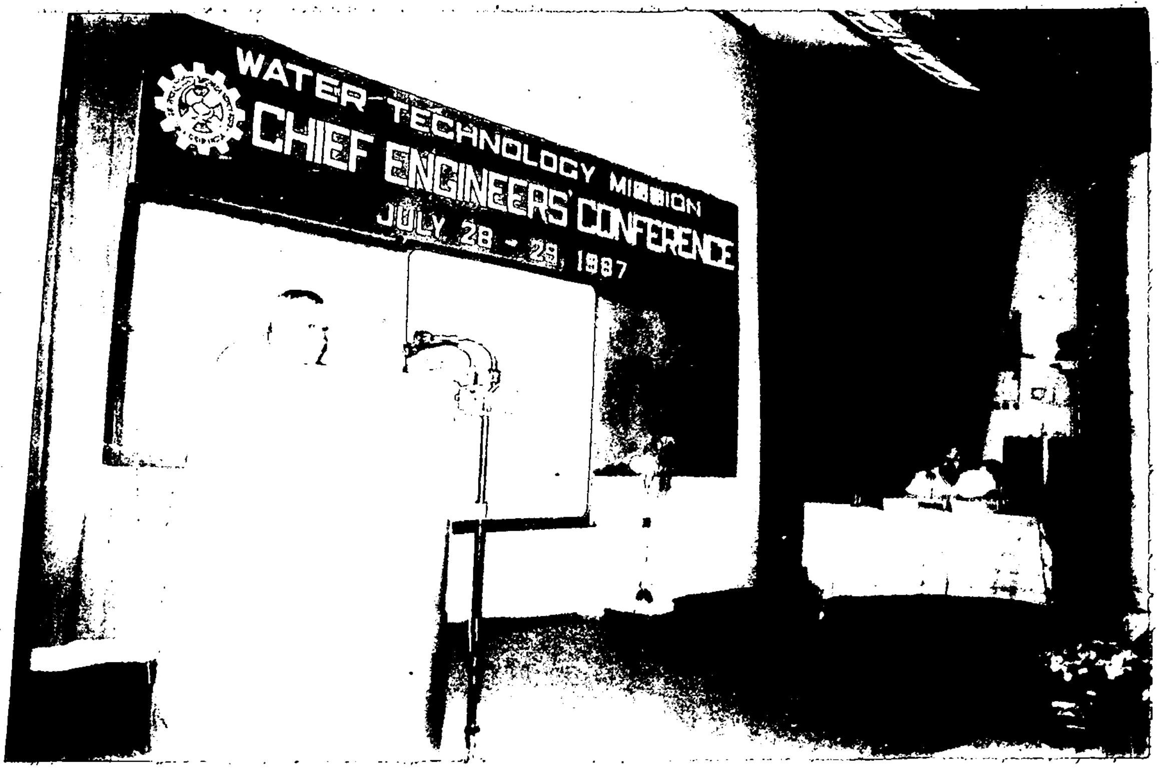
Q. In the Nalgonda Technique, alum is added to defluoridate water. Some of aluminium gets added to the water in the process. What are its effects on the health of users, and what is the limit ?

A. Alum is routinely used in conventional water treatment for coagulation. There are no reported adverse health effects of alum used in water treatment. Guidelines for water quality do not have any limit for concentrations for alum in treated water. Moreover, aluminium ion will not remain in solution in any significant concentration under the conditions of alkalinity and pH of water used for drinking water supplies.

Mr. R.V. Badve, (Pune)

Q. For the estimation of fluoride, of the SPADNS, Alizarine Red, and Specific ion meter methods, which is more accurate?

A. All these methods are accurate and their merits and limitations are well documented in standard text books, especially the "Standard Methods for Examination of Water and Wastewater". In the context of present Conference and field application of defluoridation technology, NEERI would like to recommend Specific Ion Meter method with its several advantages, most outstanding being quick and accurate results under field conditions. We have not come across any indigenous make ion selective meter. The instrument is to be imported. The Conference delegates may like to consider the recommendation that the Rural Water Supply Department of each state have at least two Ion Meters and six Fluoride Specific Electrodes for field work and cross-checking of the data obtained on portable test kits.



Mr. N.S. Lepcha, Chief Engineer, Sikkim, presiding over the Technical Session on Disinfection. Dr. S.R. Joshi, Scientist, NEERI, addressing the session.

Mr. D.C. Debnath, Chief Engineer, PHE, Tripura, presiding over the Technical Session on Iron Removal and Dr. V.P. Thergaonkar, Scientist, NEERI, addressing the Session.

IRON REMOVAL

V.P. Thergaonkar
NEERI, NAGPUR

INTRODUCTION

Iron is one of the most important and valuable of all the elements. It is essential for the nutrition and healthy development of most plants and animals, and also man, and is very widely distributed in nature. Iron is present in practically all soils, gravels, sands and rocks, some times in considerble amounts, but often only in traces. It is usually found in the form of oxides. Other common forms are ferrous carbonate and iron pyrites. Rain, percolating through soils and rocks, acquires iron in addition to other mineral constituents, depending on the nature of geological formation. There are very few waters, whether from surface or deep sources, which do not contain at least traces of iron. Iron in surface waters is mostly in insoluble or colloidal form. In deep sources, it is in dissolved state and exposure to atmosphere results in oxidation of soluble to insoluble or colloidal forms.

Iron may initially be present in piped water as derived from the source or be acquired from metals with which the water subsequently comes in contact. Hence, it is necessary to examine samples collected directly from the source. If the latter is a deep bore-hole and samples can only be obtained from the pump delivery, a series of samples should be collected at intervals throughout several hours continuous pumping at maximum capacity. Should the examination of these samples show that the amount of iron present in the water decreases rapidly as pumping proceeds, it is fairly certain that some, if not all, of the iron is derived from the metal of the bore-hole tubing, strainer and rising main. This is required to be ascertained before further action.

AREAS SHOWING IRON CONTAINING WATERS

High concentration of iron is associated with waters from shale, sand stone, and other rocks. Iron is dissolved by ground waters containing free carbon dioxide but no dissolved oxygen. Occasionally, some very deep wells in such areas also yield slightly ferruginous waters. The NEERI experience with bore-holes is that apart from dissolved iron, such waters are also characterised by very low pH, excessive dissolved carbon dioxide, trace metals such as copper, zinc, arsenic, etc., which require specific treatment to render them suitable for public supply purposes. It is, therefore, essential that all waters, confirmed ferruginous, require to be screened for other toxic substances before deciding on the type of iron removal treatment.

Assam, Meghalaya, Tripura, West Bengal, Orissa, Bihar, Uttar Pradesh, Madhya Pradesh, Maharashtra, Tamil Nadu and Kerala have been found to have ground waters bearing iron in varying concentrations requiring appropriate treatment to make them potable (Fig.1). An estimated 2900 villages/hamlets have problem of excessive iron. Various practices of iron removal are inter-related and hence must be coordinated in the process concept and in the design.

OBJECTIONS TO IRON

The presence of iron in water is objectionable owing to production of discoloration, turbidity, deposit and taste. Iron bearing waters have an astringent, metallic or bitter taste, and by combination of the iron with tannin impart an inky colour to tea infusions. Water containing iron is undesirable for culinary use, causing brown-coloured deposition on the vegetable during washing and cooking. It is also objectionable for laundry purposes and gives rise to iron-moulding on linen and other white fabrics being washed. For many industrial purposes such as papermaking, dyeing, photographic film manufacture and beverages, the water must be entirely free from iron. Even small traces of iron in

TECHNOLOGY MISSION ON DRINKING WATER

IRON PROBLEM STATES

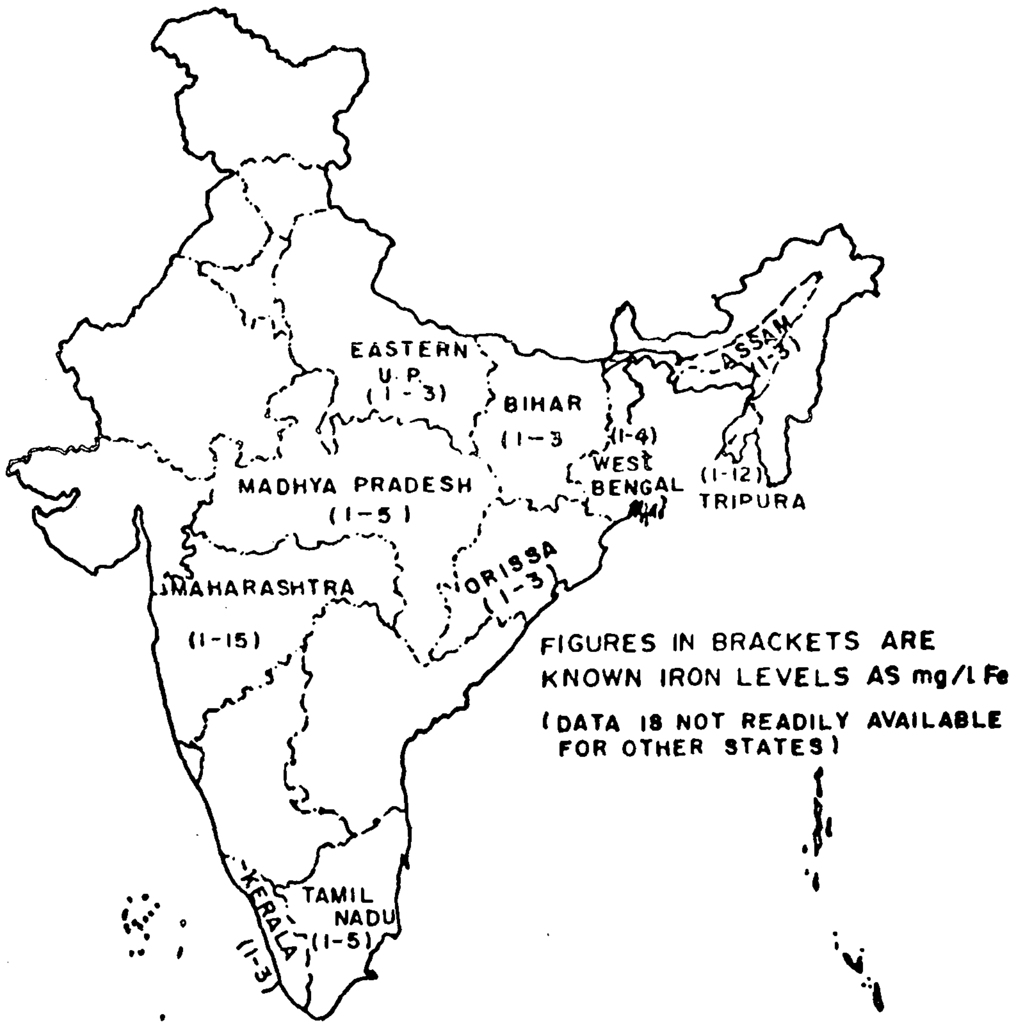


FIG. 1

water lead to accumulation of appreciable deposits in distribution mains and storage reservoirs, and these often prove troublesome to water authority and objectionable to consumer. The iron bacteria are nuisance organisms, and transform or deposit iron in the form of objectionable slime, resulting in fouling and plugging of wells and distribution systems. The bacteria also cause odour, taste, frothing colour and turbidity in waters.

LIMITS OF IRON

A toxic dose of iron is 1500 mg of $FeCl_2$ for a child. The limits for iron are hence based upon aesthetic and taste considerations. Growth of iron bacteria is experienced when iron concentration exceeds 0.2 mg/L. Ministry of Health, Government of India and Indian Standards Institution, considering the inconvenience that may arise from the presence of such small amounts of iron in public water supplies, suggested the following guidelines for iron.

Permissible	..	0.3 mg/L
Excessive	..	1.0 mg/L

When this amount is exceeded, some form of treatment is usually advisable.

NEERI'S Field Testing Method

A field testing method is developed by NEERI, which is easy to use for routine estimation, at places where elaborate facilities are not available to analyse for total iron.

Procedure :

- Take 50 ml of Water sample (representative) in a Nessler tube
- Break-open a NEERI-made 'Ferro Ampoule' and transfer the contents into the Nessler Tube and swirl to mix.

- Allow the colour to develop for 10 minutes. If iron is present, an orange-red colour will appear.
- Transfer the developed colour solution into the test tube provided in the NEERI-made colour comparator kit.
- Match the colour in the adjacent compartment and note the iron value.

METHODS OF TREATMENT

Troubles due to iron are avoided by : (i) treatment of the water before distribution, if it contains more than permissible iron, or if it is unduly corrosive to metals; (ii) use of specially selected mains, such as uPVC; (iii) avoidance of dead-end mains; and (iv) periodical flushing of mains.

The means by which iron is removed from water consist substantially of its precipitation by oxidation and removal of free carbon dioxide by aeration, followed by separation of the suspension by sedimentation and/or filtration. Aeration may suffice for the preliminary precipitation, but, when the amounts of free carbon dioxide and iron are high, or relatively soluble and complex compounds of iron are present, the addition of chemicals is necessary. Sedimentation tanks, for the removal of the bulk of the precipitate prior to filtration, are usually required when the amount of iron in the water is high. Filters will become overloaded and impossible to operate efficiently if fed with unduly turbid water.

The systems available for specific iron removal requirements are discussed below.

- Domestic treatment
- Rural water supply
- Community water supply

The supervision and operation depends on the system.

Domestic Treatment

This is for individual house-hold purpose for treatment of water with high iron content. The following are the alternatives.

- Shallow Dug Wells
- Chemical treatment with suitable doses of sodium carbonate and sodium phosphate
- Hand-operated domestic Aeration/Filtration Unit
- Muscle-power Dissolved Air Floatation Unit

Shallow Dug Wells : For private use of such wells, a diameter of 1.3 m is adequate to supply the required amounts of water, while, for larger rates of abstraction, the diameter may be increased to 2-3 m. The depth of the well primarily depends on local geo-hydrolgic condition and is limited by the cost and technical difficulties of excavation. Private wells usually have a depth less than 10 m. The construction should ensure protection against the incursion of surface drainage. The water inside the well should be chlorinated thoroughly using NEERI pot-chlorinator to guard against bacteriological contamintion. The top must not be closed with watertight cover. Water should remain in contact with air and sunlight to the extent possible. This facilitates water getting nearly saturated with air so that no iron should exist in solution. Pulley and bucket system ensures aeration of the water in the well. The dug wells will not prevent precipitated iron being carried into the water drawn and it is necessary to use domestic filters to have these precipitates removed.

Chemical Treatment : Iron present in all forms is removed by the addition of a mixture of sodium carbonate and sodium phosphate. The technique developed by NEERI comprises of addition of the chemicals to precipitate iron as insolubles followed by settling and filtration. The treatment is carried out in a 60 L bucket containing 40 L water with a tap at 10 cm above the bottom of the bucket for removal of the settled water. The concept can be extended to larger volumes of water using suitable masonry tanks built in each house.

Hand-operated Domestic Aeration/Filtration Unit : This unit was developed by NEERI and internationally referred to as Domestic Iron Removal Unit (DIRU). The unit is suitable for rural purposes, and can be built from locally available skill. Aeration of the raw water over a series of coke/marble/calcite beds is followed by slow sand filtration. After some time, a catalytic oxidation bed is formed which hastens the removal process. No chemicals are needed. The unit can be worked directly by an elevated hand-pump. Raw water containing 1-6 mg/L Fe(II) iron and 0.1-3 mg/L Mn (IV) manganese can be treated in this way at the rate of 200 L/hr.

Muscle-power Dissolved Air Floatation Unit : The Unit comprising of air saturator, and flotation tank with inbuilt filter can be fabricated with local talent. The unit is attached to a hand pump of capacity up to 500 L per operation. The desired treatment of water is achieved through the *following sequence of plant operation :*

- Raw water is filled in the air-saturator to approximately three fourth of its volume and the screw-cap is tightened. The pneumatic and the screw-cap is tightened. The pneumatic hand-pump is operated to attain a pressure of 3.5 kg/cm^2. Water becomes saturated with air at this pressure which is then led into the floatation tank through a distributor, regulated by hand-controlled shut-off valve attached to a flexible hose and on to the distributor manifold.

- The floatation tank with filter is filled with iron bearing water and air-water mix is admitted from the saturator. The micro-fine air bubbles quiescently lift the oxidised iron to the surface. The air-water mix discharge continues for nearly 20 min by which time the water in the floatation tank becomes clear and rid of iron. The unit produced water with 0.5 mg of iron form a raw water containing 5 mg/L using 2.5 L of air water mix.

Rural Water Supply

This is for small communities in rural areas, where the low density of population makes piped distribution costly. The rural population is often poor; and, particularly in subsistance farming communities, little money is available. Frequently, there are hardly sufficient funds to pay for the operation and maintenance of the water supply scheme and the small communities are unlikely to be able to meet the capital costs of their water supply without assistance from the Government. Trained personnel for the operation and maintenance may not be available in the rural areas and are to be provided.

The rural water supply scheme intends to treat raw water containing free carbon dioxide and dissolved iron and includes, hand-pumps, tray-aerators, sedimentation basin and sand filters. Design parameters for entire water facility are available for 250, 500 and 1000 population.

In making the technology choice, unnecessarily complicated designs were avoided, decreasing the cost of construction, and reducing the difficulties of operation and maintenance.

Estimated Cost for Rural Water Supply Schemes :

The capital cost and O & M cost (Rs/m^3) for the various populations is given in Table 1.

TABLE 1 : Cost Estimates for Hand Pump with Iron Removal Unit

Population	Design flow m^3/d	Capital Cost Rs.	O & M (Running Cost) Rs/d	Rs/m^3
250	10	17000	61.60	6.16
500	20	19700	81.60	4.10
1000	40	22000	112.00	2.80

Note : Capital Cost does not include Land Cost.
O & M Cost includes

i) Manpower
ii) Chemicals - sodium carbonate and bleaching powder
iii) Depreciation @ 5% p.a.
iv) Annual Interest on Capital Investment @ 12% p.a.

An Example of Cost Analysis for a Population of 250 and Water Supply of 10 m^3

Capital Cost : Hand Pump : Rs.10,000/-
Plant : Rs. 7,000/-

O & M Cost :
a) Depreciation @ 5% p.a. Rs. 850/-
b) Annual Interest @ 12% p.a. Rs. 2,040/-
c) Maintenance @ 5% p.a. Rs. 850/-
d) Cost of Chemicals p.a. Rs. 730/-
e) Manpower (two persons) p.a. Rs.16,800/-
f) Contingency @ 5% of (a to e) p.a. Rs. 1,064/-

TOTAL RS.22,334/- p.a.
or Rs.61.60 per day
ie. Rs.61.6/10
= 6.16 per m^3

Community Water Supply :

When the question of iron removal is under consideration for community water supply, it is important to decide and cover what other treatment of the water, if any, is necessary or desirable. It is, for example, inadvisable to remove the iron and yet leave sufficient free carbon dioxide to cause corrosion of mains and pipes, and the presence of considerable free carbon dioxide and toxic substances is usual in ferruginous waters.

The means by wehich iron, free carbon dioxide and other toxic substances are removed from water in community systems consist substantially of removal of free carbon dioxide, followed by oxidation, precipitation and separation of toxic substances by sedimentation and/or filtration. Aeration may suffice for the preliminary precipitation but may not be adequate when concentrations are high.

The community water supply scheme makes provision to meet these requirements and comprises of raw water storage tank, cascade tray aerators, chemical dosers, sedimentation basin, filtration and disinfection. The source of raw water is bore wells since shallow dug wells may not contain soluble iron.

Designs of the various units for community for 5, 10, and 20 m^3/hr continuous supply for 16 hr are avabilable.

Estimated Cost for Community Water Supply :

For the design flows of 5, 10, and 20 m^3/hr, the capital cost and O & M costs are given in Table 2.

TABLE 2 : Cost Estimates for Continuous Iron Removal System for Community Water Supply

Design flow	Capital Cost		O & M Running Cost	
m^3/hr	Rs./day	Rs./m^3	Rs./day	Rs./m^3
5	95000	792	235.60	2.35
10	133000	554	397.00	1.65
20	215000	448	608.00	1.26

O & M Cost includes :

1) Manpower
2) Power - 0.35 kwh
3) Chemicals - Sodium carbonate dose 50 mg/L and bleaching powder - 1-2 mg/L
4) Depreciation at 5% p.a.
5) Annual interest on capital investment - @ 12% p.a.

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DISINFECTION OF DRINKING WATER

S.R. Joshi
NEERI, NAGPUR

INTRODUCTION

In a developing country like India, biological pollution of water supplies is a major concern. It is mainly due to lack of sanitation and waste water treatment facilities and personal hygiene. The pollution of water sources by sewage or fecal matter results in entry of disease producing microorganisms making water unfit for human consumption.

Table 1 : Classification of Water Related Diseases

Sr.No.	Category	Disease	Remedy
1.	Water-borne infections	Typhoid, Cholera Jaundice, Dysentery	Microbiological improvement in water quality
2.	Water washed infection (skin, eyes)	Scabies, Trachoma	Greater volume of water for use
3.	Water based infection	Schistosomiasis Guinea worm	Protection of user and source
4.	Water related insect vectors breeding in water	Sleeping sickness Yellow fever Malaria	Water piped from sources

PATHOGENIC MICROORGANISMS :

Different groups of microorganisms which cause water borne diseases are shown in Table 2.

Table 2 : Pathogenic microorganisms causing diseases

	Organism	Disease
Bacteria :	*Salmonella*	**Eenteric fever (Typhoid, paratyphoid)**
	Shigella	**Gastroenteritis**
	Vibrio cholerae	**Dysentery Cholera**
Viruses :	**Infectious hepatitis B**	**Jaundice**
	Polio virus	**Polio**
	ECHO, Coxsackie	**Gastroenteritis**
Protozoa	*Entamoeba histolytica*	**Amoebic dysentery**
	Giardia	**Giardiasis**
	E. coli	**Gastroenteritis**
Helminths :	**Tape worm**	**Gastroenteritis**
	Round worm	

DISINFECTION :

It is the process of destruction or at least complete inactivation of harmful pathogenic microorganisms present in the water. The chemical or agent used in this process is termed as 'Disinfectant'.

Types of Disinfectants

Two types of disinfectants

1) Chemical **2) Non-chemical.**

Chemical Disinfectants :

Requirement :

* **Effective in killing pathogenic microorganisms**
* **Readily soluble**

* Not imparting taste, odour or colour to water
* Not toxic to human life
* Easy to detect
* Easy to handle, transport, apply and control
* Readily available

Types of Chemical Disinfectants :

a) Chlorine and chlorine compounds :

It is mostly used because

* It destroys microbes quickly
* Widely available
* Cost is moderate

b) Iodine :

It is not used mostly because of its limitations like :

* High doses (10-15 mg/L) requirement
* Not effective when water is coloured or turbid
* High volatality in aqueous solution

c) Potassium Permanganate :

* It is a powerful oxidizing agent
* Effective against cholera and not against other pathogenic microbes
* Leaves stains in container

d) Ozone :

* Effective against compounds that give objectionable taste or colour
* Leaves no measurable residuals
* High installation and operational cost
* Needs continuous power supply

Non-chemical Disinfectants :

Boiling : It is safe and time honoured which destroys pathogenic microorganisms. It is effective at household level but at community level.

U.V. & Gamma radiation : Light irradiation is effective for clear water and not for turbid water. It is ineffective when water contains nitrate, sulphate, ferrous ion. It does not produce any residual.

NEERI's Technology :

Most of the population in India is in rural areas where well water is the major source for drinking purposes. Well water gets contaminated because these are shallow wells and unhygienic activities such as washing, accumulation of waste water, etc., are prevalent around it. Hence, it is necessary to disinfect water continuously. Different types of Dip chlorinators which consist of a cement container and bleaching powder solution are designed through which calculated drops of chlorine solution drip in the well continuously by using a plastic tube. It chlorinates well for about 6-8 days but after that period it gets choked up due to formation of insoluble calcium carbonate. A single and double pot (Earthen) method where coarse sand and bleaching powder (3:1) mixture is used was also developed. The pot has holes (1 cm) at middle and near bottom position. Once it is lowered in the well with help of rope below the surface of water, concentrated solution of chlorine oozes out through holes and mixes with well water thus disinfecting it. It is successfully used in many community and household wells in different parts of this country.

Due to urbanization and industrialization, most of the drinking water sources are getting polluted. Though the water is treated in water treatment plant, it gets contaminated during distribution system with the result that consumer gets contaminated water. In order to make water safe, chlorine tablets and chlorine ampoules are developed and processes are patented. These are being manufactured by many entrepreneurs. In our country, chlorine tablets and ampoules are available in different forms which contain different concentrations of chlorine. (1 to 300 mg in tablet & 1 to 5 mg in ampoule) to disinfect different volumes of water.

DISCUSSION

The Chairman Mr. Lepcha commented that biological contamination of water is man made. It is through our habits and manners. He expressed the desire that the programmes under Rural Water Suppy/Sanitation Decade should come under the purview of the Technology Mission as these have a direct bearing on the Mission objectives and that there is an urgency to develop a bacteriological kit so that remedial measures can be taken.

Mr. R.P. Nanda (Hyderabad)

Q. You have said that iodine will not ensure 100% disinfection. Which are the bacteria that are not affected by iodine ? How for is the Ion Exchange's Zero 'B' efficient ?

A. Iodine being a disinfectant kills bacteria but a higher dose of above 16 ppm which is physiologically toxic is required and hence can not be used.

Mr. Amrutappa Patil (Gulbarga)

Q. Why has the use of potassium permanganate now been discontinued for disinfection ?

A. Potassium permanganate is more effective for cholera rather than for *Salmonella* and *Shigellae, E. histolytica*, etc. Moreover, higher concentration imparts colour and taste.

Mr. R.S. Nema (Shahdol)

Q. Major part of Shahdol Dist. has goitre problem due to iodine deficiency. Can the iodine or iodine with chlorine be used in hand-pumps be used as disinfectant so that iodine can solve the goitre problem? Please recommend the dose needed.

A. Iodine and chlorine in combination can be used to disinfect water. However, concentrations of both have to be worked out. This combination will help in supplementing iodine.

Dr. J.C. Shrivastava (New Delhi)

Q. Who are moulding the single and double pots for chlorination?

A. There is no central agency at present to provide such pots. NEERI supplies the necessary information on the size and quality of sand, the quantity of bleaching powder, etc., on demand.

Mr. P.R. Kulkarni (New Bombay)

Q. Why is ozonization adopted in Western countries? Is it true that chlorination may cause cancer?

A. The Western countries adopt ozonization because it is suggested that chlorination may cause formation of trihalomethane (THM) which is a carcinogenic agent. However, detailed studies on THM have not been carried out to conclusively prove its carcinogenicity.

Ms. R.V. Badve (Pune)

Q. Is there a method of differentiation of contamination due to human feces and that due to animal dung since the latter is more prevalent in rural areas ?

A. At present, there is no fool proof-method for such differentiation.

Mr. Rajendra Dayal (Lucknow)

Q. How does one disinfect hand-pump water ?

A. Hand-pumps draw water from tube-wells which are much less contaminated specially by fecal matter, hence the need for disinfection of such waters is not that acute.

Shri K.R. Bulusu suggested at the end of the discussion that water disinfected before break-point chlorination will kill the pathogenic microbes. For THM formation, one has to go beyond break-point chlorination which may not be preferable or even desirable.

TRAINING NEEDS

R. Sarin

NEERI, NAGPUR

The Department of Rural Development, Ministry of Agriculture, Govt. of India communicated in February 1986 that a Mission has been set up to have low cost science and technology solutions for overcoming the problems of fluorides, salinity, brackishness, bacterial contamination and problems related to hilly areas, deserts and tribal areas. Consequently, the Council of Scientific & Industrial Research (CSIR), in March 1986, identified National Environmental Engineering Research Institute (NEERI), by virtue of its achievements in development of products, processes and techniques for improved water quality, as one of the four institutes that will be required to play a vital role to achieve Mission objectives. NEERI has with it defluoridation, iron removal, pot-chlorination and slow sand filtration as important technologies for solving drinking water quality problems.

Knowing that NEERI will be required to closely interact with the implementing agencies for advancement of objectives of the Mission and that the availability of adequate number of personnel with requisite calibre and motivation is the success of any mission, training needs for personnel involved at different levels, i.e., management level, supervisory level, laboratory staff and operators' level were identified particularly as an important part of technology transfer.

In fact, the first step that NEERI took for this Mission was to make fully aware the Officials of Polytechnology Transfer Centres (PTC) of CSIR, as these Officials were involved in looking after the identified problem districts regarding transfer of technology. Hence, a three day awareness programme was organised at Nagpur in July 1986 for the Heads of nine PTCs of CSIR located at Ahmedabad, Bombay, Bhopal, Bangalore, Delhi, Hyderabad, Lucknow, Shillong & Trivandrum. Lectures and demonstrations were arranged throgh NEERI scientists on defluoridation, iron removal, slow sand filtration and disinfection.

Subsequently, another three-day awareness programme was organised in August, 1986 for Officials of PHE departments of ten States. Twenty Officials, two each from Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Meghalaya, Rajasthan, Tamilnadu, Uttar Pradesh, and West Bengal participated. The Officials were made aware of the water technologies available for problems related to scarcity, brackishness, salinity, excessive fluorides or iron, guinea worm control.

As at the State Department level, the initial step required for this Mission will be evaluating water quality. A number of persons, with knowledge of sampling and analysis, will be needed in the State Analytical Laboratories. Several courses have been planned to be conducted during this year. For those who are in need of obtaining detailed knowledge on water quality assessment, comprehensive training programmes of 3 weeks duration have been planned. One such was conducted in June 1987 and another will be conducted in Feb. 1988. For those who are in need of a refresher course only, five day programmes have been designed. This has been conducted in July 1987 and another is proposed for November, 1987. In these courses, the trainees get educated in analysis of physico-chemical parameters (pH, conductivity, turbidity, alkalinity, hardness, chlorides, fluorides, nitrates, sulphates, iron and manganese) and bacteriological parameters. Greater emphasis is being given on laboratory work.

Besides the above, several short duration (two days) technology demonstration programmes are being organised at Nagpur. These will be repeated in the months of September, November, 1987 and January and March, 1988.

Additionally, the individuals deputed by the State PHE Departments in connection with the establishment of District/Taluka water analysis laboratory and/or mobile water analysis unit are being provided with information on the equipment and chemicals required for water analysis in this specific Mission.

Apart from the aforesaid programmes at Nagpur. NEERI is also providing group training to personnel identified by the State agencies in the respective States as a part of technology transfer. These are directed towards generation of awareness regarding the specific technologies suitable for solving water quality problems. As such, training in these cases includes presentation of technologies in a camp and orienting the identified personnel in understanding and designing systems of treatment to suit a particular requirement. Such programme of six days duration was conducted on excessive fluoride problem at Amreli District, Gujarat State in April 1987.

The programme was basically aimed at training the representatives of the participating agencies of various States afflicted with the problem of excess fluorides in drinking water. The programme included : (i) Lecture and discussion sessions, (ii) Demonstration of technologies at the camp site. (iii) Visit to fluorosis affected villages, (iv) Demonstration of Nalgonda Technique under field condition, (v) Evaluation of water quality and fixing the dose of chemicals for the identified sources, and (vi) Public meetings and demonstration at important places.

Another training-cum-demonstration programme of five days duration on excessive iron problem was recently conducted at Agartala District (Tripura State). It was a unique programme conducted at National Level. All the ten States and a few more, to be included in this Mission later, got benefited with this programme. The programme included : (i) Lecture and discussion session, (ii) Problems due to iron in ground water and methods of removal, (iii) Analytical methods of iron estimation, (iv) Demonstration of treatment design for rural and community water supply, (v) Home designs for iron removal, (vi) Muscle power iron removal systems, (vii) Visit to the iron problem villages. The programme concluded with public meetings and popular talks

The problem of supplying adequate potable water to the community will not end with the construction of water treatment facilities. Their maintenance and operation is equally important, if not more. Unless such treatment plants are properly maintained and kept in trim operational condition, they can not deliver the desired quality of water. Again, unless they are operated in a technically sound manner, qualiity of treated water will not be of the desired level. A regular tab has to be kept on the quality of water at all stages of treatment. Thus, for effective maintenance and operation of the treatment system, a few more courses will get added to the list of those already planned.

WATER TECHNOLOGY MISSION TRAINING PROGRAMMES DURING 1987-88

In partial fulfilment of the demands for Water Technology Mission implementation, NEERI will undertake the following training programmes, for the identified staff groups of implementing agencies, on the technologies to be contributed by NEERI.

A) WATER ANALYSIS :

1) Comprehensive Training Programme (15 days duration) :

   * 8-26 June, 1987 (completed).
   * 8-26 February, 1988 (s/t adequate response : 25 participants)

2) Short-term Training Programme (5 day duration) :

   * 6-10 July, 1987 (Completed)
   * 9-13 November, 1987 (Completed)

The five day duration training covers limited physico-chemical, and bacteriological parameters (pH conductivity; turbidity; alkalinity; hardness; chlorides; fluorides; nitrates; sulphates; iron and manganese; etc.) and essential practical work and demonstration.

B) TECHNOLOGY AWARENESS

1) Defluoridation : One day duration. Fifty participants each time.

   * 16th September, 1987
   * 18th November, 1987
   * 13th January, 1988
   * 16th March, 1988

2) Iron Removal : Half-day duration. Fifty Participants each time.

   * 17th September, 1987
   * 19th November, 1987
   * 14th January, 1988
   * 17th March, 1988

3) Slow Sand Filtration : Half-day duration. Fifty participants each time.

   * 17th September, 1987
   * 19th November, 1987
   * 14th January, 1988
   * 17th March, 1988

The awareness programmes are in series so that the participants can avail of one or more in a row.

DISCUSSION

Mr. M.M. Dutta (New Delhi)

Q. Please enlighten us on post-training evaluation particularly whether there is any need for the same, it is being carried out or not and future plans regarding the same ?

A. Post-training evaluation is not done by NEERI. This should be responsiblity of the sponsoring organisations. Our future plan is to prepare a manual on O&M of treatment plants, to conduct training courses on this treatment and prepare video cassettes for field training courses.

Dr. J.C. Shrivastava (New Delhi)

Q. How to generate faith in technologies per se through training? What is the out-put of training programs? Have you developed detailed syllabi for (i) management (ii) middle and (iii) operator level? What is the percentage of practical and audio-visual aids in training ?

A. Demonstration of technology can generate faith in the developed technology. Feedback is sought from participants to know the awareness and out-put of the training programmes. Detailed syllabi are yet to be developed. At present, the percentage is 50 each for practical and class-room lectures after the audio-visuals are ready the class-room work will be 25% lectures and 25% video taped programs.

Dr. J.W. Bhatacharjee (Lucknow)

Q. Is it possible for NEERI to conduct analytical quality control scheme for samples received and analysed by PHED ?

A. NEERI is already conducting AQC lectures and practicals in its training programs.

Mr. Amrutappa Patil (Gulbarga)

Q. Do you have a follow-up action for the training programmes ? Does NEERI propose to conduct any peripatic training camp where institutional faculty are not available?

A. Follow-up action should be resposibility of the sponsoring agencies. At present, there is no proposal for a peripatic training camp but a request can always be considered.

Quantification of Problem Areas

Chairman : Gauri Ghosh

While appreciating the presentation by the NEERI Scientists during all the earlier Sessions, Shri Ghosh informed about the work done on Slow Sand Filtration by Gujarat Voluntary Agency and enquired whether it can be possible to connect their water collection ponds with the slow sand filtration system. Shri Ghosh posed the following for consideration:

Can the agencies like NREP, RSGP, etc., come together and prepare a model for the installation, operation, maintenance and evaluation?

We would like to know whether we should set up a household or community or domestic defluoridation system or should treat the water at source only.

While we talk about the fluoride problem in drinking water, we should also collect information on the fluorides consumed through food.

What are the detection systems for fluoride in water? A detailed survey and analysis of fluorosis in every district is desirable.

As regards the iron removal technology, the Chairman stressed on the development of the cost-effective solution. Help from NRDC may be sought, wherever necessary. Choice of technology should be site oriented.

M/s. Richardson and Cruddas have developed fibre glass treatment plant for iron removal. It deserves appreciation. Such approach should be encouraged.

On Defluoridation and Iron removal, he expressed concern as to why the technology has not been replicated and lack of this replication deserves indepth analysis. We must find out whether it is due to a technological gap or there exist field problems prohibiting straight replications.

Training of personnel is extremely important and it needs to be started in the right earnest.

Chief Engineers, on return, should communicate and discuss the problems with their staff to ensure their involvement and commitment to achieve desired level of implementation of these technologies.

Awareness camps should be organised on a large scale and as frequently as possible. Posters, leaflets in regional languages should be distributed on a mass scale to increase awareness and community participation.

Water Technology Mission must receive topmost priority and maximum efforts should be concentrated on implementation of projects under this banner.

State Government should undertake detailed analysis of each village and classify them as Mini-Mission, Sub-Mission and other Mission areas.

Chief Engineers should pin down the problems and submit specific project proposals to WTM.

We should explore whether it is feasible for the universities/ research institutes to pick up good students on scholarships, train them and allot them to the States.

We are thinking of creating certain positions in universities in the field of water supply and sanitation.

We are also instituting awards for the best preparation of project proposals/technical reports/scientific documents relating to Water Technology Mission.

Summing up, Shri Ghosh, the Chairman expressed that Water Technology Mission, PHEDs and NEERI (CSIR) make a heterogeneous and yet homogenous group of Scientists, Technologists and Administrators and this is the strength of the structure for successful implementation of the WTM projects.

Minimal Cost Design of Rural Water Supply Systems@

(A): Optimal Design of Branched Water Supply Networks

By Anand V. Chiplunkar[1] and P. Khanna[2]

Abstract: A rational procedure for the optimization of branched water supply networks is developed in closed form. Two case studies are presented to illustrate the procedure for the optimal design of complete gravity systems and direct pumping systems.

Introduction

As a consequence of rapid assessment of the status of drinking water supply and sanitation carried out by the Government of India along with national targets set for the decade, it is estimated that a sum of Rupees 42 billion ($1.00 = Rs9.21) will be spent during the International Water Supply and Sanitation Decade to achieve the goal of 100% coverage for rural water supply from the present 30% (4). Similar investments are envisaged in other South East Asian countries as brought out by Subrahmanyam (15). These investments highlight the urgency for research to develop simple optimization techniques useful to practicing engineers in the developing countries in the context of maximizing service to the population with limited resources.

It is customary to consider rural water supply systems as scaled down versions of urban installations requiring less engineering skill and ingenuity in design (16). The rural systems differ substantially from the urban installations which are mainly looped networks and cater to much larger population densities whereas the rural systems are predominantly dead end distributions catering to smaller population densities. The cost effective design of rural water supply systems therefore calls for a different approach.

Literature Review

Various researchers have proposed the use of mathematical programming techniques in identifying optimal solutions to rural water supply design problems. Karmeli, et al. (10) and, Robinson and Austin (13) pre-

[1]Sr. Project Engr., Dept. of Civ. Engrg., Indian Inst. of Tech., Powai, Bombay 400 076, India.

[2]Prof. of Environmental Engrg., Dept. of Civ. Engrg., Indian Inst. of Tech., Powai, Bombay 400 076, India.

Note.—Discussion open until November 1, 1983. To extend the closing date one month, a written request must be filed with the ASCE Manager of Technical and Professional Publications. The manuscript for this paper was submitted for review and possible publication on January 11, 1982. This paper is part of the Journal of Environmental Engineering, Vol. 109, No. 3, June, 1983. ©ASCE, ISSN 0733-9372/83/0003-0604/$01.00. Paper No. 18003.

@ Presented by Prof. P. Khanna, Director, NEERI, Nagpur sented a method of water distribution design networks using the theory of linear programming. Liang (12) proposed the design of conduit system by dynamic programming. Watanatada (21) formulated the design problem as a nonlinear programming problem and solved it by Variable Metric Method. All these methods involve the use of computers which are still beyond the reach of most designers in developing countries.

Tong, et al. (19) employed equivalent length method whereas Deb and Sarkar (6) proposed equivalent diameter method in the identification of the optimal solution which fail to hold under mathematical scrutiny (18).

Cowan (5) developed an optimality criterion for checking the closeness of a design to the optimal for pipes in series. With resource to this criterion, Deb (7) developed a method for optimal analysis of branched pipe network which could be solved with the help of a desk calculator. The procedure involves initially solving all the single branches in the network containing pipes in series only (not branching). This is followed by combining two single branches at a time and modifying the coefficients calculated previously for the same. Further, this linking of pairs of single branches (or modified combined pairs) is continued two at a time with recalculation of coefficients each time for all the linked single branches till the whole network is covered. In real life situations as the number of branches increase, the process of necessarily linking only two branches at a time involves increasing number of computational steps and reevaluations for same branches to obtain the final solution.

This paper presents an optimization algorithm for design of branched water supply systems using Lagrangian Multiplier Technique. The solutions are workable on calculators and obviate the requirement of computers in optimal design as also of successive reevaluations.

Optimization Approach

The Lagrangian Multiplier Technique appends the equality constraints to the objective function (cost function) through Lagrangian Multipliers to obtain the Lagrangian function. The minimization of Lagrangian function amounts to the minimization of the objective function as the constraint is satisfied. The optimal solution is achieved by taking the first partial derivative of Lagrangian function with respect to the decision variables (diameters, or diameter and pumping head in case of rural water supply systems) and the Lagrangian multipliers and equating the expressions thus obtained to zero. The solution of these equations results in a minimum cost design if the Lagrangian multipliers are positive (14).

Rural Water Supply Systems

The rural water supply systems are characterized by dead end distributions where the quantity flowing in various sections can be determined explicitly and accurately knowing the water demand at each node. The systems comprise a source of water and several draw-off points (public standposts or house connections). The distributions are single branched or multiple branched systems depending on population distribution. The rural water supply systems fall under one of the following categories:

1. Complete Gravity System: The source of water is at an elevation higher than the village so as to maintain desired terminal pressure at all times.
2. Direct Pumping System: The source of water and village are so located as to warrant pumping to ensure desired terminal pressure at all times.
3. Combined Pumping and Gravity System: This involves pumping water from the source to an elevated reservoir and then its distribution under gravity.

Single Branch Rural Water Supply Systems

Complete Gravity System.—Consider a single branch dead end system (17) as shown in Fig. 1. The source is located at the point O where an initial head h_o is available. The terminal head required at point n is h_n. There are n sections in the branch and the length and flow in ith section are L_i and Q_i, respectively.

The capital cost of pipe (including laying and jointing cost) can be expressed as

$$C_{pipe} = KD^m \quad (1)$$

in which C_{pipe} = cost of pipe per meter (including laying and jointing cost); D = internal diameter of pipe in meters; and K and m are constants depending on the material of pipe.

The total cost of pipe for the branch, shown in Fig. 1, can be expressed as

$$Z = \sum_{i=1}^{n} K\, L_i\, D_i^m \quad (2)$$

in which Z = total cost of pipe for n sections; L_i = length of ith section, in meters; and D_i = internal diameter of ith section, in meters.

The relationship for estimating the frictional head loss in ith section can be written in general as,

$$h_{fi} = \frac{L_i Q_i^p}{K_R\, C_R^p\, D_i^r} = C_i\, D_i^{-r} \quad (3)$$

in which h_{fi} = frictional head loss in ith section in meters; K_R = constant; Q_i = flow in ith section in cubic meters per second; C_R = pipe roughness coefficient; p, r = exponents; and $C_i = L_i\, Q_i^p/(K_R\, C_R^p)$.

The Modified Hazen-Williams formula (9) derived from Darcy-Weisbach and Colebrook-White equations is dimensionally homogeneous and

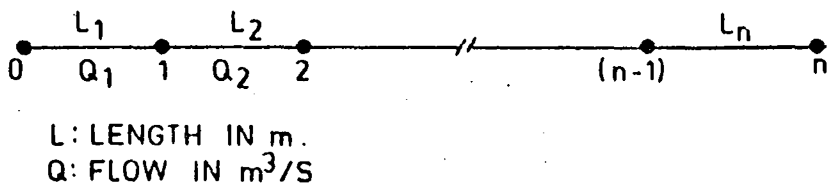

FIG. 1.—Single Branch Dead End System

therefore incorporated in this research

$$V = 143.534\, C_R\, r_h^{0.6575}\, S^{0.5525} \quad (4)$$

in which V = velocity in meters per second; C_R = pipe roughness coefficient; r_h = hydraulic radius in meters; and S = friction slope. Equation 4 can be written in the following form for High Density Polyethylene (HDPE) pipes (C_R = 1)

$$h_{fi} = \frac{L_i\, Q_i^{1.8099}}{994.62\, D_i^{4.8099}} \quad (4a)$$

Comparing with Eq. 3, the values of p, K_R, and r are 1.8099, 994.62, and 4.8099, respectively. The total frictional head loss in the branch is

$$H_{fn} = \sum_{i=1}^{n} C_i\, D_i^{-r} \quad (5)$$

The total head loss H_{fn} should be equal to the available head $(h_o - h_n)$ so as to achieve the required terminal head h_n at point n. The constraint can therefore be expressed as

$$H_{fn} = \sum_{i=1}^{n} C_i D_i^{-r} = (h_o - h_n) \quad \text{i.e.} \quad \sum_{i=1}^{n} C_i D_i^{-r} - (h_o - h_n) = 0 \quad (6)$$

Equation 6 would apply to all critical points (end points and intermediate points on high ground).

The optimization problem can be stated as that of minimizing total cost Z (Eq. 2) subject to constraint (Eq. 6). The Lagrangian function of the problem is

$$Z_1(D_i, \lambda) = \sum_{i=1}^{n} K\, L_i\, D_i^{m} + \lambda \sum_{i=1}^{n} C_i\, D_i^{-r} - \lambda(h_o - h_n) \quad (7)$$

in which Z_1 = Lagrangian function of $(n + 1)$ variables; and λ = Lagrangian multiplier.

For optima, partially differentiating the Lagrangian function Z_1 with respect to $D_i(i = 1, 2, \ldots, n)$ and equating the expression to zero

$$\frac{\partial Z}{\partial D_i} = mK\, L_i\, D_i^{m-1} - r\,\lambda\, C_i\, D_i^{-(r+1)} = 0 \quad (8)$$

Evaluating λ from Eq. 8 and substituting for C_i from Eq. 4

$$\lambda = \frac{m\, K\, L_i\, D_i^{m+r}}{r\, C_i} = \frac{K_R\, C_R^{p}\, m\, K\, D_i^{m+r}}{r\, Q_i^{p}} \quad \text{(for each } i\text{)} \quad (9)$$

In a single branch problem with one constraint the value of λ remains constant for each section. However in a system with multiple branches different values of λ are considered, as elaborated elsewhere in this paper. Equating values of λ for sections i and $i + 1$ in Eq. 9 for a single branch system

$$\frac{D_{i+1}}{D_i} = \left(\frac{Q_{i+1}}{Q_i}\right)^{N} \quad (10)$$

in which $N = p/(m + r)$. Thus as (D_i/Q_i^N) has a value invariant with respect to i

$$D_i = D_1\left(\frac{Q_i}{Q_1}\right)^N \quad (11)$$

Partial differentiation of Z_1 (Eq. 7) with respect to λ and equating the expression to zero results in constraint equation (Eq. 6). Substituting value of D_i from Eq. 11 and C_i from Eq. 3 in Eq. 6

$$\frac{\sum_{i=1}^{n} L_i Q_i^p}{K_R C_R^p}\left[D_1\left(\frac{Q_i}{Q_1}\right)^N\right]^{-r} - (h_o - h_n) = 0 \quad D_1^r = Q_1^{rN}\left[\frac{\sum_{i=1}^{n} L_i Q_i^p Q_i^{-rN}}{K_R C_R^p (h_o - h_n)}\right]$$

$$D_1 = Q_1^N\left[\frac{\sum_{i=1}^{n} L_i Q_i^{p-rN}}{K_R C_R^p (h_o - h_n)}\right]^{1/r} \quad D_1 = Q_1^N\left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{K_R C_R^p (h_o - h_n)}\right]^{1/r} \quad (12)$$

From Eqs. 11 and 12

$$D_i = Q_i^N\left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{K_R C_R^p (h_o - h_n)}\right]^{1/r} = (\mathrm{MF})Q_i^N \quad (13)$$

$$\text{in which} \quad (\mathrm{MF}) = \left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{K_R C_R^p (h_o - h_n)}\right]^{1/r} \quad (13a)$$

Equations 13 and 3 determine the optimal diameters and corresponding head losses, respectively. The solution can be easily computed on a calculator. Substituting values of constants and exponents from Eq. 4 in Eq. 13

$$D_i = Q_i^N\left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{994.62(h_o - h_n)}\right]^{0.2079} \quad (13b)$$

where $N = p/(m + r) = 1.8099/(m + 4.8099)$; $K_R = 994.62$; $C_R = 1$(HDPE pipe); and $(1/r) = 0.2079$.

Direct Pumping System.—The cost of pumping plant can be expressed as

$$C_{\mathrm{pump}} = K'(\mathrm{HP})^{m_1} \quad (14)$$

in which C_{pump} = cost of pumping plant; K' = a constant ascertained through regression analysis of the data correlating capital cost of pump with horse power; m_1 = exponent depending on type and range of pumping plant; and (HP) = horse power of pump which can be expressed as

$$(\mathrm{HP}) = \frac{\rho\, g\, Q_1 h_o}{746\, \eta} = A\, Q_1 h_o \quad (15)$$

in which Q_1 = total discharge, i.e., flow in first section of branch; h_o = initial pumping head; and $A = g/(746\eta)$ in which ρ = density of water; g = acceleration due to gravity; and η = combined efficiency of pump and motor.

$$C_{pump} = K_1(Q_1 h_o)^{m_1} \quad \text{in which} \quad K_1 = K' A^{m_1} \qquad (16)$$

The cost of power can be expressed as

$$C_{power} = A_1 Q_1 h_o \qquad (17)$$

in which C_{power} = capitalized cost of power; A_1 = a constant determined from the cost of energy, hours of pumping during a day, efficiency of pump and motor, yearly average consumption, and capitalizing factor over the design period (11). The objective function can be expressed as

$$Z = \sum_{i=1}^{n} K L_i D_i^m + K_1(Q_1 h_o)^{m_1} + A_1 Q_1 h_o \qquad (18)$$

The constant for the system remains same as that in Eq. 6. Combining Eqs. 6 and 18 to form the Lagrangian function,

$$Z_1(D_i, h_o, \lambda) = \sum_{i=1}^{n} (KL_i D_i^m + \lambda C_i D_i^{-r}) - \lambda(h_o - h_n)$$

$$+ K_1(Q_1 h_o)^{m_1} + A_1 Q_1 h_o \qquad (19)$$

Partial differentiation of Z_1 with respect to D_i, equated to zero, gives the following equation,

$$m K L_i D_i^m - r \lambda C_i D_i^{-(r+1)} = 0 \qquad (20)$$

Further solution for optimal diameter results in Eq. 13, just as in gravity flow case. Further for optimal pumping head

$$\frac{\partial Z_1}{\partial h_o} = K_1 m_1 Q_1^{m_1} h_o^{m_1-1} + A_1 Q_1 - \lambda = 0 \qquad (21)$$

$$\lambda = K_1 m_1 Q_1^{m_1} h_o^{m_1-1} + A_1 Q_1 \qquad (22)$$

$$\lambda = C_1 h_o^{m_1-1} + C_2 \qquad (23)$$

in which $C_1 = K_1 m_1 Q_1^{m_1}$; and $C_2 = A_1 Q_1$. Equating values of λ from Eqs. 9 and 23

$$C_1 h_o^{m_1-1} + C_2 = \frac{K_R C_R^p m K D_i^{m+r}}{r Q_i^p} \qquad (24)$$

Combining Eqs. 13 and 24,

$$(C_1 h_o^{m_1-1} + C_2)(h_o - h_n)^{m+r/r} = C_3 \qquad (25)$$

$$\text{in which} \quad C_3 = \frac{K_R C_R^p m K}{r} \left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{K_R C_r^p} \right]^{m+r/r}.$$

From Eq. 25, the optimum pumping head is expressed as

$$h_o = h_n + \left[\frac{C_3}{C_1\, h_o^{m_1-1} + C_2}\right]^{r/m+r} \quad \text{(26)}$$

Equations 13 and 26 determine the optimal internal diameters and pumping head respectively for this case of direct pumping. It is evident the solution is easily workable on calculators.

Combined Pumping and Gravity System.—In this case an additional factor for cost of storage reservoir is considered.

$$C_{tank} = (K_2 h_o + K_3) \quad \text{(27)}$$

in which C_{tank} = capital cost of storage reservoir; K_2, K_3 = constants depending on the capacity and type of construction of storage reservoir. Combining Eqs. 18 and 27, and solving as illustrated in the previous case, the optimum pumping head is given by

$$h_o = h_n + \left[\frac{C_3}{C_1\, h_o^{m_1-1} + C_2 + K_2}\right]^{r/m+r} \quad \text{(28)}$$

Equations 13 and 28 determine the optimal internal diameters and pumping head, respectively.

Multi-Branch Rural Water Supply Systems

Consider a simple dead end complete gravity systems with only two branches as shown in Fig. 2. The initial head is h_o and required terminal heads at points 3 and 5 are h_3 and h_5, respectively. The objective function to be minimized is

$$Z = KL_{01} D_{01}^{m} + KL_{12} D_{12}^{m} + KL_{23} D_{23}^{m} + KL_{14} D_{14}^{m} + KL_{45} D_{45}^{m} \quad \text{(29)}$$

The constraints on terminal heads of h_3 and h_5 are

$$C_{01} D_{01}^{-4.8099} + C_{12} D_{12}^{-4.8099} + C_{23} D_{23}^{-4.8099} - (h_o - h_3) = 0 \quad \text{(30)}$$

$$C_{01} D_{01}^{-4.8099} + C_{14} D_{14}^{-4.8099} + C_{45} D_{45}^{-4.8099} - (h_o - h_5) = 0 \quad \text{(31)}$$

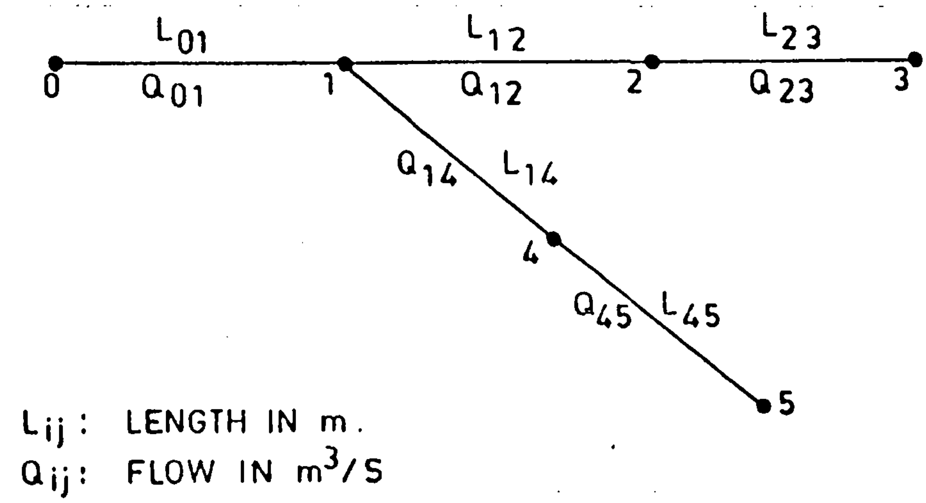

FIG. 2.—Multibranch Dead End System

Using Lagrangian multipliers λ_1, and λ_2 to append the constraints (Eqs. 30 and 31) to the objective function (Eq. 29), the Lagrangian function Z_1 is expressed as

$$Z_1 = KL_{01} D_{01}^m + KL_{12} D_{12}^m + KL_{23} D_{23}^m + KL_{14} D_{14}^m + KL_{45} D_{45}^m$$
$$+ \lambda_1 [C_{01} D_{01}^{-4.8099} + C_{12} D_{12}^{-4.8099} + C_{23} D_{23}^{-4.8099} - (h_o - h_3)]$$
$$+ \lambda_2 [C_{01} D_{01}^{-4.8099} + C_{14} D_{14}^{-4.8099} + C_{45} D_{45}^{-4.8099} - (h_o - h_5)] \quad \ldots\ldots\ldots\ldots (32)$$

Differentiating Z_1 partially with respect to the five diameter variables D_{01}, D_{12}, D_{23}, D_{14}, D_{15} and two Lagrangian multipliers λ_1 and λ_2; and equating the expressions to zero results in nonlinear equations with seven variables. The exact solution of these equations will determine the optimal diameters. Appendix I presents a case study based on the preceding approach using Brown's algorithm (3) for the solution of nonlinear equations.

As the size of the problem increases in the multibranch system, the number of nonlinear equations to be solved also increases, warranting the use of standard nonlinear algebraic equation solution methods on computer. Keeping in view the nonavailability of such computing devices to most designers in developing countries, the necessity for formulating a practical algorithm which simplifies the solution procedure without sacrificing accuracy of design becomes evident.

Any optimal solution results in continuous diameters which necessarily must be rounded off to discrete commercial sizes. This requirement has been exploited by first using simple solution procedure of single branch dead-end systems for multibranch systems and then manipulating the rounding off procedure to obtain a functional optimal solution in terms of commercially available pipe sizes, through an algorithm presented in following steps:

1. Calculation of multiplication factor for each branch: Consider, initially, each branch of the system to be independent of the others and compute the 'Multiplication Factor' (MF) for each branch (which is constant for all sections of that branch), from Eq. 13 as

$$(MF) = \left[\frac{\sum_{i=1}^{n} L_i Q_i^{mN}}{K_R C_R^p (h_o - h_n)} \right]^{1/r} \quad \ldots\ldots\ldots\ldots (33)$$

2. Calculation of multiplication factor for each section: For sections occurring in only one branch, the multiplication factor is taken as that for the branch in which it occurs. However, in case of sections common to more than one branch the maximum multiplication factor for the section is determined by comparing the multipliclation factors of all the branches in which it occurs.

3. Calculation of optimal internal diameter of each section: The theoretical optimal internal diameter of each section is computed from Eq. 13 as $D_i = Q_i^N \times$ maximum multiplication factor for the section.

4. The diameter of the section nearest to the source is rounded off to the nearest available higher commercial size.

5. The diameters of the remaining sections are then rounded off either

to the next higher or lower commercial size after taking into account the available additional residual head at the begining of the sections (due to initial rounding off to higher commercial size). Simultaneous calculation of head loss in each section is carried out using the Modified Hazen William formula (Eq. 4) and the residual head at the end of the section is estimated as available head at the begining of the section minus the head loss in the section.

6. In case of direct pumping systems or combined pumping and gravity systems the pumping head for each branch is computed by Eq. 26 and Eq. 28, respectively, and the maximum pumping head is reckoned as the system head. The diameter of each section is then estimated by Eq. 13 and subsequent rounding off to available commercial size is carried out as described in Step 5.

The choice of maximum multiplication factor for a section common to more than one branch results in the choice of a diameter which is larger than the requirement to satisfy the constraint in equality form for all branches except the critical branch (one having maximum multiplication factor). This results in increased initial available head for these branches thereby increasing the pressure surface parameter defined by Deb (8). The additional available head is utilized in this algorithm by rounding off continuous diameter of subsequent sections to next lower sizes.

In this algorithm, checks for maximum velocity constraint and maximum pressure constraint can also be incorporated during the rounding off procedure (Step 5).

A case study for complete gravity system has been presented in Appendix I which identifies and compares the two designs, namely, one obtained by the exact solution of nonlinear equations with recourse to Brown's algorithm and the other solution using the manipulative algorithm delineated above. It is interesting to note the marginal variations in theoretical continuous diameters by the two approaches which are ultimately rounded off to the same set of commercially available discrete sizes.

Another case study to illustrate the solution procedure for a direct pumping rural water supply system is detailed in Appendix II.

Conclusions

This paper presents a simple optimization algorithm for rural water supply systems using the Lagrangian Multiplier Technique. Case studies on complete gravity and direct pumping systems have also been presented to illustrate the solution procedure. The paper specifically examines the application of a simplified approach developed by Swamee, et al. (17) to multibranch systems, considering each branch to be initially independent (thereby requiring one Lagrangian multiplier) while estimating the multiplication factor for that branch and later combining all branches by choosing the maximum multiplication factor for common sections. The design identified through this simplified approach has been compared with the exact design considering all the branches simultaneously (thereby requiring as many Lagrangian multipliers as the branches). Despite a marginal difference in the theoretical optimal diameters by the two approaches, the final design remains unchanged due to the requirement of discrete commercial pipe sizes. A complete algorithm for the estimation of theoretical optimal diameters along with a procedure for rounding off to the commercial sizes to minimize the difference in the design by the two approaches has also been presented. Appendix I brings out the ease in calculation (the optimal design is achieved on pocket calculators) as compared to the requirement of solution of large number of simultaneous nonlinear equations in exact design (necessarily warranting the use of computers) without any sacrifice on accuracy of design. Such an approach is more likely to be employed by the designers in developing countries during the International Drinking Water Supply and Sanitation Decade for minimizing financial requirements in meeting the goals set by various governments and international agencies.

Acknowledgments

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Appendix I.—Case Study 1: Multibranch Complete Gravity System

The problem in this case study is illustrated in Fig. 3. The source is located at point *B*. The required terminal head at points *E*, *F*, *H*, *I*, *K*, *M*, *N* and *P* is 8 m of water head. The length and discharge in each section and relative elevation of each point are defined in Fig. 3. There are 8 branches, namely, BDE, BDF, BDGH, BDGI, BDGJK, BDGJLM, BDGJLCN, and BDGJLCP.

A regression analysis of cost of High Density Polyethylene (HDPE) pipe, including 30% of pipe cost as laying and joining cost, results in the following equation, (Eq. 1):

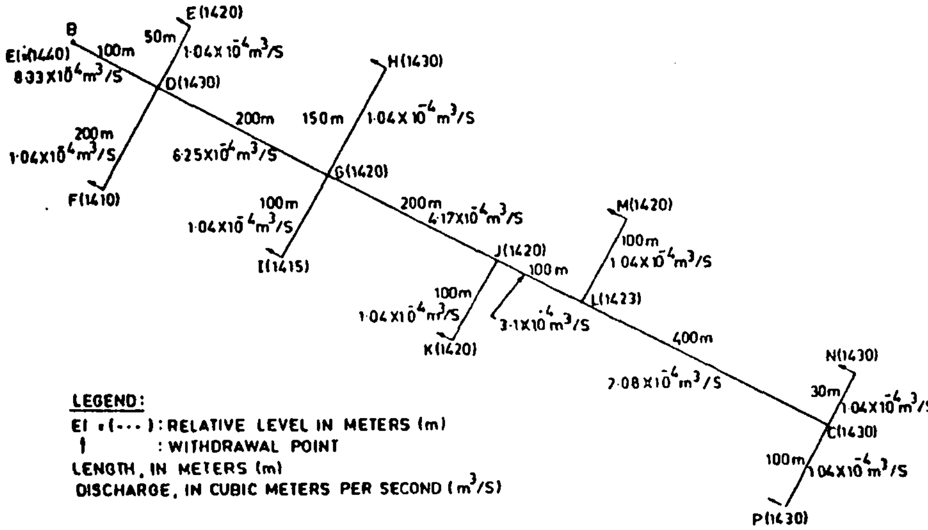


FIG. 3.—Case Study 1: Multibranch Complete Gravity System

$$C_{pipe} = 11{,}316.5\,(D)^{1.928} \qquad (34)$$

in which C_{pipe} = cost of pipe per unit length, in Rupees per meter; K = 11,316.5; and m = 1.928.

Formulating the objective function and constraints as illustrated in Eqs. 29 through 31 to form the Lagrangian function as shown in Eq. 32:

$$\begin{aligned}\text{Minimize}\quad Z_1 &= 11{,}316.5[100\,D_{BD}^{1.928} + 50\,D_{DE}^{1.928} + 200\,D_{DF}^{1.928} + 200\,D_{DG}^{1.928}\\
&+ 150\,D_{GH}^{1.928} + 100\,D_{GI}^{1.928} + 200\,D_{GJ}^{1.928} + 100\,D_{JK}^{1.928} + 100\,D_{JL}^{1.928}\\
&+ 100\,D_{LM}^{1.928} + 400\,D_{LC}^{1.928} + 30\,D_{CN}^{1.928} + 100\,D_{CP}^{1.928}] + \lambda_1[C_{BD}\,D_{BD}^{-4.8099}\\
&+ C_{DE}\,D_{DE}^{-4.8099} - (1{,}440 - 1{,}420 - 8)] + \lambda_2[C_{BD}\,D_{BD}^{-4.8099} + C_{DF}\,D_{DF}^{-4.8099}\\
&- (1{,}440 - 1{,}410 - 8)] + \lambda_3[C_{BD}\,D_{BD}^{-4.8099} + C_{DG}\,D_{DG}^{-4.8099} + C_{GH}\,D_{GH}^{-4.8099}\\
&- (1{,}440 - 1{,}430 - 8)] + \lambda_4[C_{BD}\,D_{BD}^{-4.8099} + C_{DG}\,D_{DG}^{-4.8099} + C_{GI}\,D_{GI}^{-4.8099}\\
&- (1{,}440 - 1{,}415 - 8)] + \lambda_5[C_{BD}\,D_{BD}^{-4.8099} + C_{DG}\,D_{DG}^{-4.8099} + C_{GJ}\,D_{GJ}^{-4.8099}\\
&+ C_{JK}\,D_{JK}^{-4.8099} - (1{,}440 - 1{,}420 - 8)] + \lambda_6[C_{BD}\,D_{BD}^{-4.8099} + C_{DG}\,D_{DG}^{-4.8099}\\
&+ C_{GJ}\,D_{GJ}^{-4.8099} + C_{JL}\,D_{JL}^{-4.8099} + C_{LM}\,D_{LM}^{-4.8099} - (1{,}440 - 1{,}420 - 8)]\\
&+ \lambda_7[C_{BD}\,D_{BD}^{-4.8099} + C_{DG}\,D_{DG}^{-4.8099} + C_{GJ}\,D_{GJ}^{-4.8099} + C_{JL}\,D_{JL}^{-4.8099}\\
&+ C_{LC}\,D_{LC}^{-4.8099} + C_{CN}\,D_{CN}^{-4.8099} - (1{,}440 - 1{,}430 - 8)] + \lambda_8[C_{BD}\,D_{BD}^{-4.8099}\\
&+ C_{DG}\,D_{DG}^{-4.8099} + C_{GJ}\,D_{GJ}^{-4.8099} + C_{JL}\,D_{JL}^{-4.8099} + C_{LC}\,D_{LC}^{-4.8099}\\
&+ C_{CP}\,D_{CP}^{-4.8099} - (1{,}440 - 1{,}430 - 8)] \qquad (35)\end{aligned}$$

in which λ_1, λ_2, λ_3, λ_4, λ_5, λ_6, λ_7, and λ_8 = Lagrangian Multipliers.

The Lagrangian function Z_1 is a function of 21 variables, namely, 13 diameter variables and 8 Lagrangian multipliers. Partially differentiating Z_1 with respect to each of the 21 variables and equating the expressions to zero results in 21 simultaneous nonlinear equations. Computer solution of these equations was obtained using Brown's algorithm (3) and summarized in Table 1. The solution obtained with the algorithm developed in this paper is presented in Table 1.

A comparison of the solutions by the two approaches in columns 2 and 4 of Table 1 brings out that optimal diameters obtained for the sections in the main branch BDGJLCP are almost same. It is only the diameters of the end sections that have been overestimated in column 4 as compared to the optimal diameters determined by the more rigorous procedure in column 2. However, this difference is rectified in the rounding off procedure while obtaining commercial pipe sizes where the additional head thus generated allows the freedom to round off the optimal diameter to lower pipe sizes. Hence the final solution obtained in terms of the commercial pipe sizes is same by the two approaches.

Appendix II.—Case Study 2: Direct Pumping System

The problem in case study 2 is illustrated in Fig. 4. The source is located at O and the required terminal head at points 4, 6, and 7 is 8 m each. There are three branches in the system, namely 01234, 01256, and 01257.

TABLE 1.—Summary of Results for Complete Gravity Rural Water Supply System

Section (1)	Optimal diameter by Brown's algorithm, in millimeters (2)	Maximum multiplication factor (3)	Optimal diameter through algorithm developed in this paper (4)	Commercial size, in millimeters (5)	Head loss for internal diameter of adopted commercial size, in meters (6)	Residual head, in meters (7)
BD	56.20	2.77	55.87	75	0.15	9.85
DE	10.20	1.32	15.23	20	1.91	17.94
DF	11.98	1.25	14.42	20	7.63	22.22
DG	52.01	2.77	51.71	63	0.43	19.42
GH	20.46	2.36	27.23	32	0.33	9.09
GI	11.02	1.49	17.19	20	3.82	20.60
GJ	46.30	2.77	46.38	63	0.20	19.22
JK	12.00	1.74	20.08	20	3.82	15.40
JL	42.85	2.77	42.93	50	0.19	16.03
LM	12.03	1.78	20.54	20	3.82	15.21
LC	38.41	2.78	39.00	50	0.36	8.67
CN	24.21	2.75	31.73	25	0.36	8.31
CP	31.09	2.77	31.96	32	0.22	8.45

Assuming the rate of interest, I = 9%; the life of HDPE pipe; n_1 = 50 yr; the depreciation cost; p_1 = 0.5%; and salvage value of pipe K_s as zero; the annual cost can be written as (11)

$$\text{Annual cost} = C\left[\frac{I(I+1)^{n_1} - K_s}{(I+1)^{n_1} - 1}\right] + \frac{p_1}{100} = 0.0912768\,C \qquad (36)$$

in which C = capital cost. Annual cost of pipe A_2, including 30% laying and jointing cost

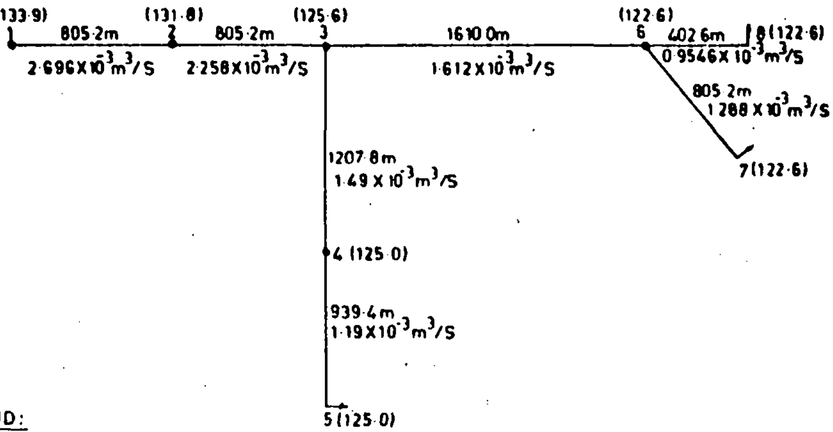
$$A_2 = 1032.93\,(D)^{1.928} \qquad (37)$$

in which K_s = 1032.93; and m = 1.928. The annual cost of pumping plant, A_3, for 16 hour pumping; 70% combined efficiency η of pump motor; 50% standby in brake horse power; rate of interest, I = 9%; life of pump n_1 = 15 yr; depreciation cost p_1 = 3% and salvage value of pump 10% can be expressed using Eq. 16 as,

$$A_3 = 1767.97(Q_1 h_o)^{0.7217} \qquad (38)$$

in which K_1 = 1767.97; m_1 = 0.7217; and h_o = total pumping head = (frictional head loss − head available due to elevation difference between source and terminal point + required terminal head of 8 m).

The annual cost of energy, A_4; at the rate of Rupees 0.18/kwhr; for 16 hr pumping during a day; 70% efficiency of pump and motor; and a yearly averaging water consumption factor of 80% can be expressed using Eq. 17 as



LEGEND:
El=(...) : RELATIVE LEVEL IN METERS (m)
↑ : WITHDRAWAL POINT
LENGTH, IN METERS (m)
DISCHARGE, IN CUBIC METERS PER SECOND (m^3/S)

FIG. 4.—Case Study 2: Direct Pumping System

$$A_4 = 11775.8(Q_1 h_o) \tag{39}$$

in which A_1 = 11775.8. Solving Eq. 26 for each branch independently, the optimum pumping head for different branches is determined as

Branch 01234: h_o = 110.6 m Branch 01256: h_o = 118.7 m

Branch 01267; h_o = 106.9 m .... (40)

To satisfy the requirements of all branches the maximum pumping head is h_o = 118.7 m is considered in design.

The optimal diameters are obtained by solving Eq. 13 and design summary is listed in Table 2. The actual pumping head required after rounding off the theoretical diameters to the commercial sizes is estimated as 118.7 m.

TABLE 2.—Summary of Design for Direct Pumping Rural Water Supply System

Section (1)	Optimal internal diameter, in millimeters (2)	Commercial Size, in Millimeters		Head loss, in meters (5)	Residual head, in meters (6)
		Internal diameter (3)	Nominal diameter (4)		
01	51.10	53.3	63	24.1	96.7
12	48.72	53.3	63	17.5	85.4
23	42.96	42.2	50	38.1	47.9
34	40.44	42.2	50 (450 m)	9.5 + 30.4	8.0
		33.7	40 (489.4 m)	= 39.9	
25	44.50	42.2	50	58.3	30.1
56	41.90	42.2	50	19.4	10.7
57	37.87	33.7	40	16.7	13.4

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Appendix IV.—Notation

The following symbols are used in this paper:

A = $(\rho\, g)/(746\, \eta) = 13.14/\eta$;
A_1 = constant;
A_2 = annual cost of pipe;
A_3 = annual cost of pumping plant;
A_4 = annual cost of energy;
C = capital cost;
C_1 = $K_1\, m_1\, Q_1^{m_1}$;
C_3 = $(K_R\, C_R^p\, m\, K)/r\, [\Sigma_{i=1}^n (L_i\, Q_i^{mN})/K_R\, C_R^p]^{(m+r)/r}$;
C_i = $(L_i Q_i^p)/(K_R C_R^p)$;
C_R = coefficient of roughness;
D_i = internal diameter of pipe of ith section in meters;
(HP) = horsepower of pump;
h_o = initial available head in meters;
h_n = terminal head in meters;
H_{fn} = total frictional headloss in the branch in meters;
h_{fi} = frictional head loss in ith section in meters;
I = rate of interest;
K_s = salvage factor;
K, K', K_1, K_2, K_3 = constants;
K_R = constant in headloss equation;
L_i = length of ith section in meters;
m, m_1 = constant;
(MF) = multiplication factor, $[\Sigma_{i=1}^n L_i Q_i^{mN}/K_R C_R^p (h_o - h_n)]^{1/4}$;
N = $p/(m + r)$;
n_1 = life of component under consideration;
p = exponent of flow in head loss equation;
p_1 = depreciation cost;
Q_i = flow in ith section in cubic meters per second;
r = exponent of diameter in head loss equation;
r_h = hydraulic radius in meters;
S = friction slope;
V = velocity in meters per second;
Z = objective function;
Z_1 = Lagrangian function;
λ_i = Lagrangian multiplier;
ρ = density of water; and
η = combined efficiency of pump and motor.

Subscript

i = ith section.

(B) : MODIFIED HAZEN-WILLIAMS FORMULA

By Akalank K. Jain,[1] D. M. Mohan,[2] and P. Khanna[3]

INTRODUCTION

An environmental engineer is often faced with problems of design and analysis while dealing with water supply systems. Design problems involve decision making with respect to pumping heads and pipe diameters in the distribution system, whereas analysis problems refer to the evaluation of a given network for flow rates in different pipes and pressure heads at different locations. The design problems require the optimal synthesis of water systems in the context of modern times. Analysis problems reduce to the solution of a set of algebraic equations obtained from the continuity and resistance relationships describing the hydraulic system.

The basic requirement in both analysis and design problems is the estimation of frictional resistance to flow of water in the pipeline. The Hazen-Williams formula (or a nomograph thereof) is widely used in the solution of these problems. This formula has several limitations, and its continued usage can be attributed to the lack of appreciation of these by design engineers or for the lack of a better alternative. Use of this formula for the usual range of pipe diameters and certain flow conditions may result in errors of the order of ±50% or larger in the estimation of frictional resistance.

This paper addresses itself to the development of a simple, more rational and accurate formula, similar in form to that of the Hazen-Williams. The proposed formula expresses a relationship for the velocity in terms of pipe diameter (or hydraulic radius), friction slope, and a coefficient of roughness which is a function of pipe diameter and its material, velocity of flow, and the water

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[1]Sr. Research Fellow, Dept. of Civ. Engrg., Univ. of Roorkee, Roorkee, on deputation from Government Coll. of Engrg., and Tech., Raipur (M.P.), India.

[2]Post-Grad. Student, Environmental Engrg., Univ. of Roorkee, Roorkee, India.

[3]Reader in Civ. Engrg., Univ. of Roorkee, Roorkee, India.

temperature (thus its viscosity). The new formula is based on an explicit relationship for pipe diameter and the Colebrook equation for friction factor.

Limitations of Hazen-Williams Formula

Limitations Inherent in Formula.—The Hazen-Williams formula can be expressed as

$$V = C' r^{0.63} S^{0.54} \qquad (1)$$

The Chezy formula is written as

$$V = C r^{0.5} S^{0.5} \qquad (2)$$

If b is a multiplying factor to be used with Eq. 1 in order that Eqs. 1 and 2 yield the same velocity for $C = C'$:

$$b\, r^{0.63} S^{0.54} = r^{0.5} S^{0.5}$$

which yields $b = r^{-0.13} S^{-0.04}$ (3)

Hazen-Williams assumed $r = 1$ ft (0.3 m), and $S = 1/1{,}000$, to evaluate the

TABLE 1.—Percentage Errors in Estimation of Velocity by Use of Hazen-Williams Formula

S number (1)	Pipe diameter, in inches (millimeters) (2)	Hydraulic radius, r, in feet (meters) (3)	Slopes S (4)	Percentage error in velocity (5)	Percentage error in frictional resistance (6)
1	4 (100)	1/12 (0.025)	0.33/1,000	−30.74	−57.0
2	4 (100)	1/12 (0.025)	1/1,000	−27.60	−51.1
3	12 (300)	1/4 (0.76)	1/1,000	−16.60	−30.7
4	72 (1,800)	1.5 (0.46)	1/1,000	+5.50	+10.2
5	72 (1,800)	1.5 (0.46)	7.8/1,000	+14.32	+26.5
6	72 (1,800)	1.5 (0.46)	300/1,000	+32.45	+60.2

multiplying factor b as 1.318, resulting in the commonly used form of the Hazen-Williams formula, in feet per second:

$$V = 1.318\, C r^{0.63} S^{0.54} \qquad (4)$$

in which C = Chezy's coefficient, usually called the Hazen-Williams constant. In S.I. units, Eq. 4 can be expressed as:

$$V = 0.85\, C r^{0.63} S^{0.54} \qquad (5)$$

Despite the caution given by its authors (12) against the universal usage of

Eq. 4, design engineers have indiscriminately used the Hazen-Williams formula over wide ranges of diameters and friction slopes. This practice may result in an error of the order of ±30% in the evaluation of velocity consequent to an error in the multiplying factor b due to change in r and S.

The errors involved in the determination of velocity and frictional resistance employing Eq. 4 are presented in Table 1 for limiting diameters and slopes tabulated by Hazen and Williams (12). The corresponding error in frictional resistance for a given pipe is 1.85 times the error in velocity. From Eq. 4, for a given pipe, $V = K S^{0.54}$, in which K is a constant differentiating, $dV = 0.54 K S^{-0.46} dS$, and $dS/S = 1.85\, dV/V$.

TABLE 2.—Percentage Errors in Estimation of Darcy's f by Hazen-Williams Formula

S number (1)	Pipe material (2)	Roughness height, k, in meters (3)	Hazen-Williams coefficient, C (4)	Pipe diameter, in millimeters (5)	Velocity, in meters per second (6)	Percentage error (7)
1	Cast-iron new coated	0.00015	130	100	3.0	−13.00
2	Cast-iron new coated	0.00015	130	1,500	0.3	+26.19
3	Cast-iron old (moderate corrosion, 30 yr age)	0.0024	100	100	3.0	−39.00
4	Cast-iron old (moderate corrosion, 30 yr age)	0.0024	100	1,500	0.3	+32.52
5	Concrete new	0.000035	130	100	3.0	−12.92
6	Concrete new	0.000035	130	1,500	0.3	+34.92
7	Steel new	0.00006	140	100	3.0	−9.22
8	Steel new	0.00006	140	1,500	0.3	+17.00

Comparison of Hazen-Williams C with Darcy's Friction Factor f.—The Darcy-Weisbach expression is

$$H = f \frac{L}{d} \frac{V^2}{2g} \qquad (6)$$

The Hazen-Williams equation (Eq. 5) can be rearranged as

$$H = \frac{6.8}{C^{1.85}} \frac{L}{d^{1.165}} V^{1.85} = \frac{6.8}{C^{1.85}} \frac{2g\,L}{(V^{0.15} d^{0.15})\, d^{0.015}\, d} \frac{V^2}{2g} \qquad (7)$$

Comparing Eqs. 6 and 7, and setting $\nu_{20} = 10^{-6}$ m²/s, and $g = 9.81$ m/s²

$$f = \frac{1{,}059}{R^{0.15} C^{1.85} d^{0.015}} \qquad (8)$$

in which R = the pipe Reynolds number = Vd/ν. The term $1/d^{0.015}$ is very close to unity even for pipes of large diameter and can be ignored. One can write:

$$f = \frac{1{,}059}{R^{0.15}\,C^{1.85}} \qquad (9)$$

The Colebrook-White equation for transition region of turbulent flow in commercial pipes is available in the implicit form as

$$\frac{1}{f^{0.5}} = -2\log\left(\frac{k}{3.7d} + \frac{2.51}{R\,f^{0.5}}\right) \qquad (10)$$

An explicit and accurate equivalent of Eq. 10 has been developed by the first writer (4) as

$$\frac{1}{f^{0.5}} = 1.14 - 2\log\left(\frac{k}{d} + \frac{21.25}{R^{0.9}}\right) \qquad (11)$$

A comparison of friction factors, calculated from Eq. 9 (for the Hazen-Williams C) and Eq. 11, for four different commercial pipes has been made and the

TABLE 3.—C_R Values for Cast-Iron (New Coated) Pipes, k = 0.00015 m

Diameter, in millimeters (1)	Velocity, in meters per second						
	0.3 (2)	0.9 (3)	1.2 (4)	1.8 (5)	2.4 (6)	3.0 (7)	6.0 (8)
100	0.9524	0.9089	0.8922	0.8659	0.8459	0.8299	0.7786
200	0.9760	0.9291	0.9117	0.8470	0.8641	0.8477	0.7953
300	0.9865	0.9379	0.9202	0.8927	0.8720	0.8554	0.8025
400	0.9927	0.9428	0.9249	0.8972	0.8763	0.8596	0.8064
500	0.9967	0.9459	0.9279	0.9000	0.8790	0.8623	0.8089
600	0.9950	0.9480	0.9299	0.9019	0.8809	0.8641	0.8106
700	1.0000	0.9495	0.9313	0.9032	0.8821	0.8653	0.8117
800	C_R = 1.0	0.9514	0.9323	0.9042	0.8837	0.8662	0.8125
900	C_R = 1.0	0.9524	0.9330	0.9049	0.8842	0.8668	0.8131
1,000	C_R = 1.0	0.9524	0.9336	0.9054	0.8845	0.8673	0.8135
1,100	C_R = 1.0	0.9527	0.9340	0.9057	0.8847	0.8676	0.8138
1,200	C_R = 1.0	0.9529	0.9342	0.9060	0.8849	0.8678	0.8140
1,300	C_R = 1.0	0.9531	0.9344	0.9061	0.8850	0.8680	0.8141
1,400	C_R = 1.0	0.9532	0.9346	0.9346	0.8850	0.8681	0.8142
1,500	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142
1,600	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142
1,700	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142
1,800	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142
1,900	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142
2,000	C_R = 1.0	0.9532	0.9346	0.9063	0.8850	0.8681	0.8142

errors in the estimation of f (and therefore in the estimation of frictional resistance) by the use of the Hazen-Williams C are presented in Table 2.

Limitations of Hazen-Williams Coefficient C.—It may be brought out that the Hazen-Williams C is considered independent of pipe diameter, velocity of flow, and viscosity (8), whereas C must depend on relative roughness and Reynolds number, to be truly representative as a friction coefficient. This point has been emphasized by other researchers also (2,3,5,10,11).

It can thus be seen from the foregoing that the error inherent in the use of the Hazen-Williams equation is due to two independent reasons: (1) The change in the value of multiplying factor b with r and S; and (2) change in the value of the coefficient C with the pipe diameter and flow conditions. The

TABLE 4.—C_R Values for Cast-Iron (Old) Pipes, k = 0.0024 m (Moderate Corrosion, 30 yr Age)

Diameter, in millimeters (1)	Velocity, in meters per second						
	0.3 (2)	0.9 (3)	1.2 (4)	1.8 (5)	2.4 (6)	3.0 (7)	6.0 (8)
100	0.6552	0.6886	0.7170	0.5485	0.5325	0.5203	0.4841
200	0.7025	0.6311	0.6130	0.5881	0.5709	0.5578	0.5190
300	0.7261	0.6532	0.6335	0.6078	0.5900	0.5765	0.5364
400	0.6657	0.6466	0.6203	0.6203	0.6022	0.5884	0.5475
500	0.7518	0.6753	0.6559	0.6293	0.6293	0.5969	0.5554
600	0.7599	0.6826	0.6630	0.6361	0.6175	0.6034	0.5614
700	0.7664	0.6884	0.6687	0.6415	0.6227	0.6085	0.5661
800	0.7718	0.6932	0.6733	0.6459	0.6270	0.6127	0.5701
900	0.7762	0.6972	0.6772	0.6497	0.6307	0.6163	0.5734
1,000	0.7801	0.7007	0.6805	0.6529	0.6338	0.6193	0.5762
1,100	0.7834	0.7037	0.6834	0.6556	0.6365	0.6219	0.5786
1,200	0.7863	0.7063	0.6860	0.6581	0.6388	0.6242	0.5808
1,300	0.7889	0.7086	0.6882	0.6602	0.6409	0.6263	0.5827
1,400	0.7912	0.7107	0.6903	0.6622	0.6428	0.6281	0.5844
1,500	0.7933	0.7126	0.6921	0.6639	0.6445	0.6298	0.5860
1,600	0.7952	0.7143	0.6937	0.6655	0.6461	0.6313	0.5874
1,700	0.7970	0.7158	0.6953	0.6670	0.6475	0.6327	0.5887
1,800	0.7987	0.7173	0.6966	0.6683	0.6488	0.6340	0.5898
1,900	0.8000	0.7186	0.6977	0.6695	0.6500	0.6351	0.5909
2,000	0.8014	0.7198	0.6991	0.6707	0.6511	0.6362	0.5919

resultant error will be a combination of the errors arising from these reasons, some idea about which can be obtained from Tables 1 and 2.

Proposed Formula

The explicit relationship for pipe diameter for turbulent flow in smooth pipe, obtained by Swamee and the first writer (9), and the Colebrook's equation for friction factor have been used in the derivation of a simple and accurate formula that expresses the velocity in terms of the pipe diameter, friction slope, and a roughness coefficient. The explicit equation for pipe diameter (9) for smooth-turbulent flow was obtained by the application of equations of continuity, Darcy-Weisbach and Colebrook-White, and is $d_* = 0.66\,\nu_*^{0.04}$. The exact exponent of ν_* was obtained as 0.0394 and as such

$$d_* = 0.66\,\nu_*^{0.0394} \qquad (12)$$

in which $\nu_* = \nu \left(\dfrac{1}{gSQ^3} \right)^{0.2}$ . . . . (13)

$d_* = d \left(\dfrac{gS}{Q^2} \right)^{0.2}$ . . . . (14)

From Ref. 9, the velocity can be expressed as

$$\frac{V}{(gdS)^{0.5}} = -2^{1.5} \log \left[\frac{k}{3.7d} + \frac{1.78\nu}{d(gdS)^{0.5}} \right] \quad \text{. (15)}$$

Eq. (15) was obtained as a closed-form solution for velocity using the equations of continuity, Darcy-Weisbach, and Colebrook.

TABLE 5.—C_R Values for Concrete (New) Pipes, k = 0.000035 m

Diameter, in millimeters	Velocity, in meters per second						
	0.3	0.9	1.2	1.8	2.4	3.0	6.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
100	C_R = 1.0	C_R = 1.0	0.9960	0.9821	0.9694	0.9581	0.9156
200	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9909	0.9775	0.9657	0.9223
300	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9935	0.9798	0.9677	0.9239
400	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9943	0.9803	0.9682	0.9241
500	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9944	0.9802	0.9681	0.9237
600	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9936	0.9798	0.9675	0.9231
700	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9930	0.9795	0.9668	0.9223
800	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9923	0.9785	0.9661	0.9215
900	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9916	0.9778	0.9653	0.9207
1,000	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9916	0.9770	0.9645	0.9199
1,100	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9909	0.9762	0.9637	0.9190
1,200	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9929	0.9755	0.9629	0.9182
1,300	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9895	0.9742	0.9621	0.9174
1,400	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9888	0.9740	0.9614	0.9167
1,500	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9881	0.9733	0.9606	0.9159
1,600	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9874	0.9726	0.9599	0.9152
1,700	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9868	0.9719	0.9592	0.9144
1,800	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9861	0.9712	0.9585	0.9137
1,900	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9855	0.9705	0.9578	0.9130
2,000	C_R = 1.0	C_R = 1.0	C_R = 1.0	0.9848	0.9699	0.9572	0.9124

Formula for Pipe Diameter.—Using Eqs. 12, 13, and 14, one can write

$$\left.\begin{aligned} &d \left(\frac{gS}{Q^2} \right)^{0.2} = 0.66\, \nu^{0.0394} \left[\left(\frac{1}{gSQ^3} \right)^{0.2} \right]^{0.0394} \\ &\text{from which} \quad d = \frac{0.66\, \nu^{0.0394}\, Q^{0.3764}}{(gS)^{0.208}} \end{aligned}\right\} \quad \text{. (16)}$$

Eq. 16 can be used to evaluate the pipe diameter in smooth-turbulent flow for given liquid, flow rate, and friction slope.

HAZEN-WILLIAMS FORMULA

Modified Hazen-Williams Formula.—Eq. 16 can be rearranged in the form of Hazen-Williams equation as

$$V = \frac{3.83\, d^{0.6575}\,(gS)^{0.5525}}{\nu^{0.105}} \qquad (17)$$

Eq. 17 is derived from Eq. 12 and, as such, is applicable to smooth turbulent flow only. In order to obtain a relationship for turbulent flow in general (smooth,

TABLE 6.—C_R Values for Steel (New) Pipes, k = 0.00006 m

Diameter, in millimeters (1)	Velocity, in meters per second						
	0.3 (2)	0.9 (3)	1.2 (4)	1.8 (5)	2.4 (6)	3.0 (7)	6.0 (8)
100	0.9942	0.9766	0.9658	0.9466	0.9304	0.9166	0.8687
200	C_R = 1.0	0.9905	0.9789	0.9587	0.9420	0.9279	0.8790
300	C_R = 1.0	0.9973	0.9838	0.9631	0.9461	0.9318	0.8828
400	C_R = 1.0	0.9985	0.9861	0.9651	0.9480	0.9336	0.8842
500	C_R = 1.0	1.0000	0.9873	0.9661	0.9488	0.9343	0.8848
600	C_R = 1.0	C_R = 1.0	0.9879	0.9665	0.9491	0.9346	0.8850
700	C_R = 1.0	C_R = 1.0	0.9881	0.9666	0.9492	0.9346	0.8849
800	C_R = 1.0	C_R = 1.0	0.9881	0.9662	0.9490	0.9344	0.8847
900	C_R = 1.0	C_R = 1.0	0.9880	0.9662	0.9487	0.9341	0.8844
1,000	C_R = 1.0	C_R = 1.0	0.9877	0.9659	0.9484	0.9338	0.8840
1,100	C_R = 1.0	C_R = 1.0	0.9875	0.9656	0.9480	0.9333	0.8836
1,200	C_R = 1.0	C_R = 1.0	0.9871	0.9652	0.9476	0.9329	0.8831
1,300	C_R = 1.0	C_R = 1.0	0.9867	0.9647	0.9471	0.9324	0.8827
1,400	C_R = 1.0	C_R = 1.0	0.9864	0.9643	0.9466	0.9320	0.8822
1,500	C_R = 1.0	C_R = 1.0	0.9860	0.9638	0.9466	0.9315	0.8817
1,600	C_R = 1.0	C_R = 1.0	0.9855	0.9634	0.9457	0.9310	0.8812
1,700	C_R = 1.0	C_R = 1.0	0.9851	0.9629	0.9452	0.9305	0.8807
1,800	C_R = 1.0	C_R = 1.0	0.9847	0.9624	0.9447	0.9300	0.8803
1,900	C_R = 1.0	C_R = 1.0	0.9843	0.9620	0.9447	0.9296	0.8798
2,000	C_R = 1.0	C_R = 1.0	0.9838	0.9615	0.9438	0.9291	0.8793

transition, or rough), a coefficient or roughness, C_R, may be introduced in Eq. 17

$$V = \frac{3.83\, C_R\, d^{0.6575}\,(gS)^{0.5525}}{\nu^{0.105}} \qquad (18)$$

For water temperature = 20° C ($\nu = 10^{-6}$ m²/s), and g = 9.81 m/s²

$$V = 143.534\, C_R\, r^{0.6575}\, S^{0.5525} \qquad (19)$$

The coefficient of roughness, C_R = 1 for smooth pipes and $C_R < 1$ for pipes other than smooth. Dividing Eq. 18 by $(gdS)^{0.5}$ and equating to Eq. 15

$$C_R = \frac{-2(2)^{0.5}}{3.83\, \mathrm{R}_R^{0.105}} \log\left(\frac{k}{3.7d} + \frac{1.78}{\mathrm{R}_R}\right) \qquad (20)$$

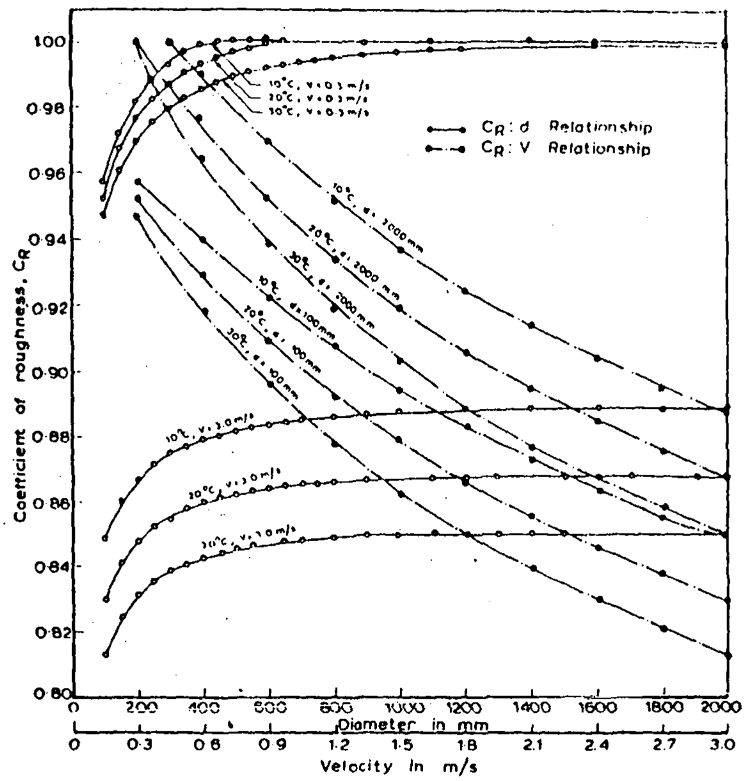

FIG. 1.—Effect of Water Temperature on Coefficient of Roughness for Cast-Iron (New) Pipes

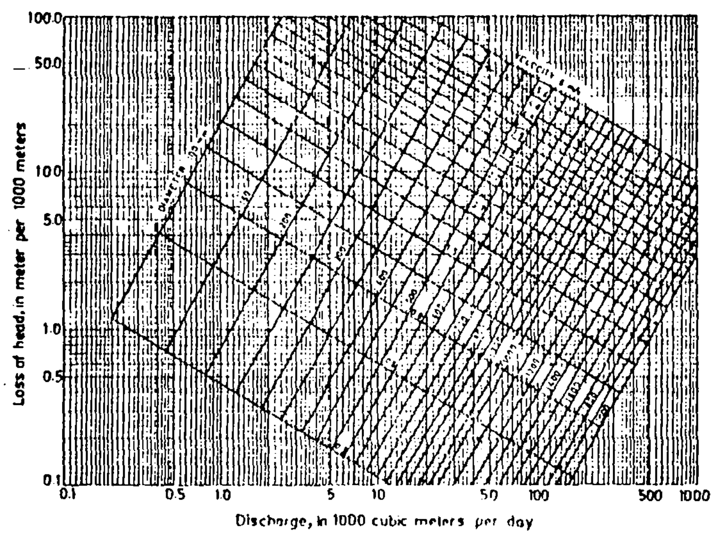

FIG. 2.—Nomograph for Loss of Head for Flow of Water (20° C) for Smooth Pipes (C_R = 1) (For C_R 1; Multiply Given Q or V by $(1/C_R)$ to find S; or Multiply Found Q or V by $(C_R/1)$ for Given S)

in which $R_R = d(gdS)^{0.5}/\nu$, a Reynolds number based on $(gdS)^{0.5}$ as the characteristic velocity. Thus C_R is a function of pipe material and diameter, velocity of flow, and temperature of water. Also by rearranging Eq. 18:

$$S = \frac{V^{1.81}\nu^{0.19}}{11.37\, g\, C_R^{1.81} d^{1.19}} \qquad (21)$$

Eq. 21 can be used to determine the friction slope (and the frictional resistance) for given liquid, pipe diameter and its material, and the flow rate.

Coefficient of Roughness.—Eq. 20 was used to evaluate the coefficient of roughness, C_R, for known conditions of the flow and the pipe. The pipe diameters and the velocities were selected from the range of these variables commonly used in water supply practice; the diameters were varied from 100 mm to 2000 mm, the velocities from 0.3 m/s to 6.0 m/s. The roughness height, k, for different pipe materials was selected from published literature and the friction slope used in Eq. 20 was determined using the Darcy-Weisbach equation for head loss. The friction factor was computed from the explicit equation, Eq. 11, developed by the first writer (4), which computes f to within 1% of the corresponding Colebrook value.

The coefficient of roughness has been estimated for cast-iron (new coated), cast-iron (old), concrete (new), and steel (new) pipes, and presented in Tables 3-6 for 20° C. The roughness values, k, have been adopted from Ackers (1) for cast-iron (new and old), and steel (new) and from Perkins (7) for concrete (new) pipes.

The effect of viscosity on C_R values has been depicted in Fig. 1 for cast-iron (new) pipes. A perusal of this shows the marginal effect of water temperature on C_R values. The maximum variation in C_R for a temperature range of 10° C-30° C is 4.5%, for 2,000-mm diam pipes at a velocity of flow of 3 m/s. In the light of this revelation, C_R values at an average temperature of 20° C have been presented.

The effect of age on roughness in the calculation of C_R values has been taken from Lamont (6), in the preparation of Table 4.

The coefficient of roughness has been computed for the full range of velocities and pipe diameters but only representative values have been furnished in Tables 3-6.

Nomograph Based on New Formula

Design and analysis problems traditionally involve the estimation of frictional resistance for a large number of pipe lines with a Hazen-Williams nomograph. In keeping with this practice, the new formula has been presented in the form of a nomograph drawn for a smooth pipe ($C_R = 1$) for flow of water at 20° C. In the solution of problems for pipes with $C_R < 1$, the flow or velocity need to be modified as shown on the nomograph in Fig. 2.

Conclusions

A modified Hazen-Williams formula based on the explicit relationships for pipe diameter and friction factor, in conjunction with the Darcy-Weisbach equation, has been derived. A coefficient of roughness has been incorporated in this formula, which is dependent on the pipe material and diameter, velocity of flow, and temperature of water. The representative C_R values for some commercial pipes have been tabulated. A nomograph based on the new formula has been appended.

Appendix I.—References

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Appendix II.—Notation

The following symbols are used in this paper:

b = multiplying constant;
C, C', C_R = coefficient of roughness;
d = pipe diameter;
f = Darcy's friction factor;
g = acceleration due to gravity;
H = loss of head;
k = roughness height;
k/d = relative roughness;
L = length of pipe;
Q = discharge;
R = VD/ν = Reynolds number;
R_R = $d(gdS)^{0.5}/\nu$;
r = hydraulic radius;
S = friction slope;
V = velocity of flow;
ν = kinematic viscosity;
ν_{20} = kinematic viscosity at 20° C; and
$*$ = subscript for nondimensional quantities.

DISCUSSION

Mr. Rashid Ahmed (Port Blair)

Q. What type of pipe do you propose for seismic belt? Kindly elucidate.

A. Non rigid flexible pipe materials would be better for seismic regions. However, the selection should be based on ranking matrix that evaluates various alternatives for desirable attributes including structural requirements for seismic regions.

Mr. V.K. Jain (Bhopal)

Q. Would it be possible to devise nomographs for gravity and pumping system for different pipe materials in common use ?

A. A general nomograph is available for optimization of gravity and pumped systems for $C_R=1$. Use of this nomograph for other materials warrants appropriate modifications which are available in such text books as Water Supply Engineering by Fair, Geyer and Okun.

Mr. M.S. Miglani (Gurgaon)

Q. It appears that the case studies have been made on HDPE pipes. What should be the constants and the results in respect of AC and PVC pipes ?

A. C_R values for AC and PVC pipe are available in the background literature. The constants for cost have been evaluated through regression analyses.

Mr. C.J. Mathews (Trivandrum)

Q. Have you prepared a Flow Chart based on the modified formula? If so, could you make it available ?

A. The nomograph based on modified Hazen Williams formula is available in the background literature. CPHEEO is considering incorporation of this formula and nomograph in their current revision of Manual on Water Supply and Treatment.

Q. Is it possible to prepare computer programmes for the proposed design ?

A. Computer programmes have been developed using modified Hazen Williams formula for the design of rural and urban water supply systems.

Q. Very often, it is not possible to locate source at the centre. What is your suggestion in such a case ?

A. The water supply source should be as close to the centre of distribution area as possible. Any deviation from the centre would mean additional cost. The planning process therefore must look into this issue.

Q. The cost of treatment of water and pumping hours will also contribute towards the total cost of the scheme. Is it considered ?

A. The algorithm for combined pump and gravity system incorporates pumping schedule as could be seen in the background literature.

RECOMMENDATIONS

DEFLUORIDATION

1. Two tier system, viz., domestic and community level be followed for application of Nalgonda Technique.

2. A State will identify two sites where NEERI, in collaboration with Public Health Engineering Department (PHED), will instal demonstration plants.

3. Regional/State level defluoridation camp will be organised at the district headquarters indicated by the States. The duration will be for two days.

4. Cost of demonstration plants would be debited to Technology Mission funds.

5. NEERI, in collaboration with PHED will prepare District, State and National maps to indicate problem zones.

6. There is a need to establish fluorosis index for India and this can be a joint activity by ICMR, NEERI, State Public Health Organisation and PHED under the Technology Mission Programme.

DISINFECTION

1. Chlorination is the best method and should be practised.

2. Single/double pot chlorination, use of chlorine ampoules and tablets should be encouraged in rural areas and district authorities may take appropriate action.

3. Locally available products like earthen pots could be tried.

4. To ensure regular supply of chlorine tablets and solution, suitable mechanism to release know-how on chlorine tablet manufacture at district level (cottage industries) be finalised as early as possible. Department of Industries can take necessary action.

IRON REMOVAL

1. State Governments (Chief Engineers) will select sites for installation of different types of iron removal plants.

2. Three sources should be tried, viz., shallow tube well, deep tube well, and sanitary dug-well.

3. State Government will complete civil works in 60 days in consultation with NEERI, if required.

4. Efficiencies of the domestic iron removal unit, muscle power unit, traditional iron removal unit of tray, cascade, and sprinkler aerators will be studied by NEERI for 60 days after completion of the plant.

5. The open dug sanitary well will be monitored for its reliability as a source, bacterial contamination and iron concentration.

6. The performance data of community iron removal plants will be analysed for arriving at the most economic solution for the situation in a particular State, within 30 days of the performance evaluation.

7. Modifications, as incorporated by different PHEDs, will also be suitably incorporated in a few plants.

8. NEERI will instal suitable iron removal plants at Jagdishpur, Raigarh, and Dadura villages in Mirzapur district (UP).

9. Regional iron removal camp of two days will be organised in U.P. before December 1987.

SLOW SAND FILTRATION

1. Slow Sand Filtration Process, a single step treatment, is cost-effective up to 8 MLD and is one of the technologies for rural water supply.

2. Horizontal flow free filtration, river bed filtration, etc., should be studied in case of highly turbid water and the cost-effectiveness be worked out.

3. In case pre-treatment is required, alternative process like contact flocculation, tube or plate settlers and dual media filter be studied for their comparative performance and the least cost solution be evolved. Initial capital cost and maintenance cost should be considered.

4. Performance evaluation of existing Slow Sand Filtration plants in the country should be undertaken.

5. The feasibility of dovetailing of the construction of slow sand filter with the RLEFP & NREP programme should be explored.

TRAINING NEEDS

1. NEERI will impart training with the objective of training the trainers and further training will be the responsibility of respective States.

2. A basic Manual on Operation and Maintenance of Treatment Plants will be brought out by NEERI. Further adoptions in regional languages will be prepared by the individual States.

3. NEERI shall assist the strengthening of training to be conducted by States by providing expert faculty for delivering lectures.

4. NEERI will provide expertise to States for establishment of water quality assessment laboratories.

5. Two day conference on Training Needs for Development of Human Resources for Technology Mission activities is to be organised by NEERI during 1987.

MINIMAL COST DESIGN OF RWSS

The State PHED should apply the model for design of a rural water supply scheme, in collaboration and consultation with NEERI.

GENERAL

The following was ratified :

i) The recommendations arrived at the First Regional Seminar for Southern States/Union Territories at Gandhigram (Tamil Nadu) from 17-19 July, 1987.

ii) The annual plan (1987-88) of Technology Advisory Groups I, II, III and IV.

iii) The targets arrived at for scientific source funding.

iv) The Sub-Missions on control of fluorosis, eradication of guinea worm, removal of excess iron, and desalination of water.

v) Eleven mini-mission project districts.

iv) Necessity for improvements in traditional methods of water purification.

vii) NEERI should finalise codification of various technological inputs with special reference to specifications and costing.

viii) The national standards for various technological inputs should be developed by the Bureau of Indian Standards.

LIST OF DELEGATES* FROM N E E R I

HEADQUARTERS & ZONAL LABORATORIES

HQrs, NAGPUR

1) Professo P.Khanna
   Director
2) Mr. K.R. Bulusu
3) Dr. P.V.R. Subrahmanyam
4) Dr. K.P. Krishnamoorthi
5) Mr. A.D. Bhide
6) Dr. V.P. Thergaonkar
7) Mr. R. Paramasivam
8) Dr. K.L. Saxena
9) Mr. S.K. Gadkari
10) Dr. A.S. Bal
11) Dr. V.R. Bhave
12) Shri R.K. Saraf
13) Shri P.K. Yennawar
14) Dr. S.N. Kaul
15) Dr. S.D. Badrinath
16) Dr. R. Sarin
17) Dr. M.V. Nanoti
18) Dr. S.R. Joshi
19) Dr. S.P. Pande
20) Dr. M.Z. Hasan
21) Mr. M.V. Mhaisalkar
22) Dr. (Mrs) I.S. Jayangouder
23) Mr. N.G. Swarnakar

Zonal Labs.

1) Dr. H.C. Arora
   DELHI.
2) Dr. M. Vittal Rao
   HYDERABAD.
3) Mr. P. Nema
   AHMEDABAD.
4) Mr. R.C. Dixit
   DELHI.

* S.No.2 to 22 of Hqrs and 1 to 4 at Zonal Labs. are SCIENTISTS.
S. No. 23 Workshop Superintendent.

LIST OF DELEGATES

1) Mr. M.S. Virdi
Project Officer
CSIR Polytech. Transfer Centre
BHOPAL - 462 003.

2) Mr. H. Nath
Additioanl Chief Engineer
P.H. Engg. Dept.
SHILLONG - 793 001.

3) Mr. Amruthappa Patil
Executive Director
Technology Mission
P.H. Engg. Dept.
GULBARGA (KARNATAKA)

4) Mr. Rajendra Dayal
Chief Engineer
U.P. Jal Nigam
LUCKNOW - 226 001.

5) Mr. P.L. Ganguly
Officer-on-Special Duty,
Irrigation, Flood Control and
P.H. Engg. Dept.
AGARTALA - 799 006.

6) Mr. B.K. Surana
Superintending Engineer
P.H. Engg. Dept.
NAGAUR (RAJASTHAN)

7) Mr. S.C. Tyagi
Executive Engineer
P.H. Engg. Dept.
AIZAWL - 796 701.

8) Mr. K. Naishadhan
Deputy Chief Engineer
Kerala Water Authority
CALICUT (KERALA)

9) Mr. K.N. Chawla
Area Manager
Sintex Plast Containers
KALOL - 382 721.

10) Mr. S.S. Bola
Surerintending Engineer (Planning)
P.H. Engg. Dept.
GURGAON (HARAYANA)

11) Mr. D.C. Debnath
Chief Engineer
Irrigation,
Flood Control
& P.H. Engg. Dept.
AGARTALA - 799 006.

12) Mr. S.K. Tiwari
Chief Engineer, N.R.D.C
Chanakya Bhavan,
Africa Avenue
NEW DELHI - 110 021.

13) Mr. B. Zahid Husain
Executive Engineer
Zilla Parishad,
P.H. Engg. Dept.
RAICHUR (KARNATAKA).

14) Ms R.V. Badve
Ground Water Survey
& Dev. Agency
PUNE - 411 005.

15) Mr. C.J. Mathews
Managing Director
Kerala Water Authority
TRIVANDRUM - 695 033.

16) Mr. V.K. Jain
Superintending Engineer
P.H. Engg. Dept.
BHOPAL (M.P.)

17) Mr. R.P. Dubey
Executive Director
Technology Mission
P.H. Engg. Dept.
JHABUA (M.P.)

18) Mr. S.C. Malvia
Executive Engineer
P.H. Engg. Dept.
RAJGARJH (M.P.)

19) Mr. R.S. Nema
Executive Engineer
P.H. Engg. Dept.
SHAHDOL (M.P.)

20) Mr. M.M. Datta
Deputy Director (PHE)
Department of Rural Development
Ministry of Agricultrue
Krishi Bhavan
NEW DELHI - 110 001.

21) Mr. M.R. Parihar
Executive Director
Technology Mission
P.H. Engg. Dept.
BARMER (RAJASTHAN)

22) Mr. N.S. Lepcha
Chief Engineer
Rural Development Department
GANGTOK - 737 101.

23) Mr. P.R. Kulkarni
Chief Engineer (Rural)
Maharashtra Water Supply &
Sewerage Board, CIDCO Bhavan
NEW BOMBAY - 400 614.

24) Mr. S. Mukherjee
Superintending Engineer
PH.H. Engg. Dept.
PO. KONNAGAR (WEST BENGAL)

25) Mr. G. Ghosh, IAS
Joint Secretary
Department of Rural Development
Ministry of Agriculture
Krishi Bhavan
NEW DELHI - 110 001.

26) Mr. G. Hanumanth Rao
Superintending Engineer
P.H. Engg. Circle
GULBARGA (KARNATAKA)

27) Dr. J.C. Shrivastava
Joint Adviser & Coordinator, WTM
CSIR, Anusandhan Bhavan
Rafi Marg
NEW DELHI - 110 001.

28) Mr. Mohd. Inamul Haq
Chief Engineer,
Panchayat Raj (RWS)
Hyderguda
HYDERABAD - 500 029.

29) Mr. Rashid Ahmed
Public Works Department
Public Health Branch
PORT BLAIR - 744 101.

30) Mr. S.S. Miglani
Executive Director
Technology Mission
P.H. Engg. Dept.
GURGAON (HARYANA)

31) Miss Pia Hold
Denmark Sofegedi
1418, Copenhagen
Technical University
COPENHAGEN, DENMARK

32) Mr. G.B. Mishra
Deputy General Manager
Richardson & Cruddas Ltd.
F-3, M.I.D.C.
NAGPUR - 440 016.

33) Mr. K.P. Nambiar,
Executive Engineer
Public Works Department
GOA - 403 602.

34) Mr. C.B. Devda
Superintending Engineer
Gujarat Water Supply &
Sewerage Board
Jasoda Bhavan
BHUJ - 370 001.

35) Mr. N.C. Trehan
Superintending Engineer
P.H. Engg. Dept.
NURPUR - 176 202.

36) Mr. N.B. Vimal Kumar
Executive Engineer
Zilla Parishad
P.H. Engg. Dept.
DHARWAD (KARNATAKA)

37) Mr. S.S. Tikekar
Senior Geologist
Ground Water Survey
& Dev. Agency
NAGPUR - 440 010.

38) Dr. A.G. Bhole
Professor in Civil Engg.
V.R.C.E., NAGPUR - 440 010.

39) Mr. S.N. Ghosh
Superintending Engineer
P.H. Engg. Deptt.
CALCUTTA - 700 001.

40) Mr. A.D. Ubhayakar
Branch Manager
Ion-Exchange Limited
V.S. Road, Prabhadevi
BOMBAY - 400 023.

41) Mr. R.E. Sinha
Executive Director
Technology Mission
P.H. Engg. Deptt.
D.A.A.D. Office
KORAPUT (ORISSA)

42) Mr. R.B. Purkayastha
Superintending Engineer
P.H. Engg. Deptt.
SHILLONG - 793 001.

43) Mr. K.G. Walekar
Deputy Director
Ground Water Survey
Development
NAGPUR 440 010.

44) Mr. S.K. Chakrabarty
Superintending Engineer
Rural Works Department
ITANAGAR - 792 111.

45) Mr. V.K. Singh
Chief Engineer
P.H. Engg. Deptt.
IMPHAL - 795 001.

46) Mr. H.B. Belorkar
Chief Engineer
Empress Mills
NAGPUR - 440 018.

47) Mr. R.P. Nanda
Assistant Executive
Engineer
Office of C.E. (PR)
Hyderguda
HYDERABAD - 500 029.

48) Dr.(Mrs.) J.W. Bhattacharjee
Scientist,
Industrial
Toxicological
Research Centre,
LUCKNOW - 226 001.