Journal of Hydrology, 51 (1981) 319—328
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

DESIGN, CONSTRUCTION AND OPERATION OF A NEW FILTER APPROACH FOR TREATMENT OF SURFACE WATERS IN SOUTHEAST ASIA

R.J. FRANKEL

SEATEC International, Consulting Engineers, Bangkok (Thailand)

(Accepted for publication October 10, 1980)

ABSTRACT

Frankel, R.J., 1981. Design, construction and operation of a new filter approach for treatment of surface waters in Southeast Asia. In: L.R. Beard (Guest-Editor), Water for Survival. J. Hydrol., 51: 319—328.

A simple, inexpensive, and efficient method of water treatment for rural communities in Southeast Asia was developed using local materials as filter media. The filter utilizes coconut fiber and burnt rice husks in a two-stage filtering process designed as a gravity-fed system without the need for backwashing, and eliminates in most cases the need of any chemicals. The first-stage filter with coconut fiber acts essentially as a substitute for the coagulation and sedimentation phases of conventional water-treatment plants. The second-stage filter, using burnt rice husks, is similar to slow sand filtration with the additional benefits of taste, color and odor removals through the absorption properties of the activated carbon in the medium. This paper reports on the design, construction costs, and operating results of several village size units in Thailand and in the Philippines.

INTRODUCTION

In 1972, the author introduced the development of a new filter approach in Thailand which on a laboratory scale appeared to have wide applicability for both water purification and wastewater treatment in Southeast Asia (Frankel and Sevilla, 1973). The filter utilizes local materials that are widely available, principally burnt rice husks and shredded coconut fiber, and both inexpensive enough to discard after use, thus eliminating backwashing. The media are used in series so that filtration alone can do the job in most cases without use of chemicals.

The raw water from a surface stream, pond or shallow well, is first passed through shredded coconut fiber, which achieves an initial reduction in turbidity and suspended solids removal, then passed through burnt rice husks, which achieves the second or polishing stage in removing residual turbidity and bacteria. Generally no chemicals are needed, but in certain cases some coagulants might be needed to enhance removals of colloidal materials. The first-stage filter with coconut fiber is found to act essentially as a substitute for the coagulation and sedimentation phases of conventional

0022—1694/81/0000—0000/$02.50

water-treatment plants. The second-stage, using burnt rice husks, is similar to slow sand filtration. However, in addition to achieving removals by the process of filtration, the burnt rice husks achieves some additional removals of taste, color and odor through the process of absorption, similar to the use of activated carbon.

Pilot-plant testing of the two-stage filtration system began in 1973 in the Lower Mekong Basin countries. The scope included field testing of the units to determine filter efficiencies, effluent quality, lengths of filter run and operational problems, and to test the acceptance of the treated water by the villagers.

Pilot-plant testing began in the Philippines in early 1976 after an initial training program with the Bicol River Basin Development Program in the design, construction and operation of the units. Based on the experiences in the Lower Mekong Basin countries, improvements were incorporated in the units built in the Philippines to enhance operational simplicity of the filters.

The two filters in series generally produce a clear effluent ⩽ 5 JTU*. The final effluent is generally free of color, odor, and is of an agreeable and acceptable taste to the villagers where it is used for drinking and cooking. Bacteria removals average 60—90% without the use of any disinfectant. By the addition of a trace of chlorine in the storage tank, the water produced is potable by the World Health Organization (W.H.O.) International Drinking Water Standards.

FILTER PLANT DESIGN

Several village size units, ranging in capacity of 1.0—15.0 $m^3 hr.^{-1}$ were constructed in the Lower Mekong River Basin countries and in the Philippines. Two-stage filtration, using two separate gravity-fed filters in series, was typical for all filter plants. The construction materials were generally wood for the support structure (except for the large 15.0-$m^3 hr.^{-1}$ unit which used circular concrete filter tanks), concrete jars for the filter boxes (concrete pipe sections and galvanized iron tanks were used also), PVC pipes, rubber-ball valve controls or overflow outlets, and gasoline-operated pumps for the power source. A summary of the filter plants constructed, their locations, the year constructed, their capacities and capital costs are shown in Table I.

Design of the units is based on a filtration rate of 1.25—1.5 m^3 per square meter of filter surface per hour ($m^3 m^{-2} hr.^{-1}$) (~0.6 $gal. ft.^{-2} min.^{-1}$) and a filter medium depth of 60 cm minimum in each filter jar or tank. This filtration rate is ~10 times more rapid than that used for slow sand filters. The media generally require changing once every 3—5 months depending on the level of turbidity in the raw water. The coconut fiber can be washed to

* JTU = Jackson turbidity units.

TABLE I

List of two-stage filter plant installations in Southeast Asia, capital and operating costs

Filter plant location	Year built	Water source	Capacity of unit	Persons served	Capital costs		Operation costs*[1]
					(US$ $m^{-3} hr.^{-1}$)	(US$ per cap.)	(US$ per family per month)

ce husks, is similar
ıg removals by the
dditional removals
ı, similar to the use

gan in 1973 in the
testing of the units
of filter run and
eated water by the

976 after an initial
nt Program in the
the experiences in
ncorporated in the
city of the filters.
ıent ⩽ 5 JTU*. The
ı agreeable and ac-
king and cooking.
ıy disinfectant. By
e water produced is
rnational Drinking

$-15.0\ m^3\ hr.^{-1}$ were
s and in the Philip-
filters in series, was
ere generally wood
$^{-1}$ unit which used
er boxes (concrete
PVC pipes, rubber-
ated pumps for the
ed, their locations,
shown in Table I.
$-1.5\ m^3$ per square
$ft.^{-2}\ min.^{-1}$) and a
jar or tank. This
or slow sand filters.
nths depending on
r can be washed to

TABLE I

List of two-stage filter plant installations in Southeast Asia, capital and operating costs

Filter plant location	Year built	Water source	Capacity of unit	Persons served	Capital costs		Operation costs*1
					(US$ $m^{-3}\ hr.^{-1}$)	(US$ per cap.)	(US$ per family per month)
Nong Khaem, Thailand	1972	tributary canal, Chaophya River	1.5	orchid farm	350	—*2	—
Ban Som, Thailand	1973	surface stream	1.5	800	425	0.80	0.30
Ban Nong Suang, Thailand	1973	surface pond	15.0	2,000	525	3.90*3	0.35
	1975	surface pond	1.0	300	300	1.00	n.a.
Kambaul, Cambodia	1973	surface pond	1.5	800	160	0.30	0.35
Hamlet Long Thong, Vietnam	1973	Mekong River	1.5	500	350	2.60	0.50
San Francisco, Canaman, Philippines	1976	Bicol River	3.0	400	670	5.00*4	0.30
Balagbag, Milaor, Philippines	1976	surface stream	3.0	400	650	5.00	0.15
San Juan, Magarao, Philippines	1976	surface stream	3.0	300	650	6.50	n.a.

n.a. = not available.
*1 Based on a gasoline-operated pump for each unit, operator's salary where applicable, pump repairs and medium replacement.
*2 Unit used to provide $10\ m^3\ day^{-1}$ for 500,000 potted orchids plus resident worker families.
*3 Unit operated as a "contact" filter using $100-120\ mg\ l^{-1}$ of alum as coagulant.
*4 Philippine units constructed to withstand typhoons.

clean out entrapped mud and re-used in the filter jars. The top 10 cm of burnt rice husks are scrapped off and discarded to waste. New burnt rice husks are added to top up the medium to the desired depth.

In most of the filter units, no chemicals were utilized, either for coagulation or disinfection. Filtration alone was utilized as the treatment process to simplify operation procedures and to gain acceptance by the village leaders. However, with burnt rice husks as a filtering medium, the process includes significant absorption capability for taste, odor and color removal. The plant at Ban Nong Suang, Thailand, was an exception however, where the system was used as an "improved contact-filtration" unit wherein a flocculating chemical (aluminum sulfate) was added to the raw water prior to first-stage filtration using shredded coconut fibers. With the raw-water turbidity in the range of 300—600 JTU, a coagulant was required to enlarge the particle size permitting improved by filtration within the media. This filter unit was used to test the feasibility of extending the range of raw-water qualities capable of being treated by the filter media through the use of small amounts of chemical coagulants. Chlorination of the water, although necessary to achieve international bacteriological standards, was not included in the filter plants in the Lower Mekong Basin countries because of strong objections from local villagers and because of the complications of supplying and feeding a proper chlorine dosage in remote villages. The filter units in the three villages of the Bicol river basin included a simple chlorinator in the storage jars for final disinfection of the filtered water to produce a potable product. Chlorinated water was more readily accepted by the Filippinos.

FILTER OPERATION

Ban Som, Thailand

The filter unit at Ban Som, serving a village of some 800 inhabitants, has been under surveillance for over two years (Frankel, 1974). The two filters in series each have $\sim 1.0\,m^2$ of filter area each and treat the raw water at a filtration rate of $1.5\,m^3\,m^{-2}\,hr.^{-1}$. Water quality of the treated water vs. that of the raw water is shown in Fig. 1, in terms of turbidity removals covering some 18 months of operation. The filter media were changed five times in this period of time. The shredded coconut fibers were removed from the first filter unit, washed in the raw-water source, and returned to the filter box on three of these occasions. New coconut fiber was placed in the filter only twice. The top 10 cm depth of burnt rice husks were removed and replaced with fresh burnt rice husks on four of the five times, and completely replaced only once. The gasoline pump broke down on seven occasions during this period of operation and a new one was purchased in July 1975. The filtered water was readily accepted by the villagers for all household uses. Effluent turbidity was generally less than 5 JTU and showed an average removal of over 90%.

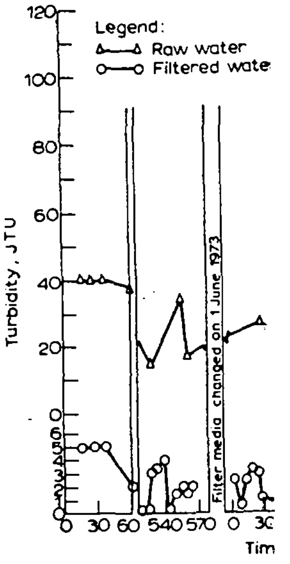

Fig. 1. Efficiency of pil
Korat, Thailand.

TABLE II

Bacterial removals of the

Raw water, range (MPN p
Average value (MPN per 1
Filtered water, range (MP
Average value (MPN per 1
Percent removal
Deviation (MPN per 100
95% confidence internal
Number of samples

MPN = most probable nu

The bacteriological
1975 are represented
were similar to what
equal to removals ach
disinfection is requir
the degree of purifica
cost. The effluent wa

The top 10 cm of
[illegible]e. New burnt rice

either for coagula-
[illegible]eatment process to
the village leaders.
[illegible]e process includes
[illegible]removal. The plant
where the system
[illegible]ein a flocculating
prior to first-stage
[illegible]er turbidity in the
ge the particle size
[illegible]lter unit was used
ualities capable of
amounts of chem-
[illegible]essary to achieve
n the filter plants
ections from local
[illegible] feeding a proper
[illegible]ree villages of the
[illegible]rage jars for final
[illegible]duct. Chlorinated

[illegible]0 inhabitants, has
). The two filters
[illegible]he raw water at a
treated water vs.
[illegible]rbidity removals
were changed five
[illegible]re removed from
urned to the filter
[illegible]laced in the filter
[illegible] removed and re-
[illegible]s, and completely
[illegible] seven occasions
[illegible]sed in July 1975.
for all household
howed an average

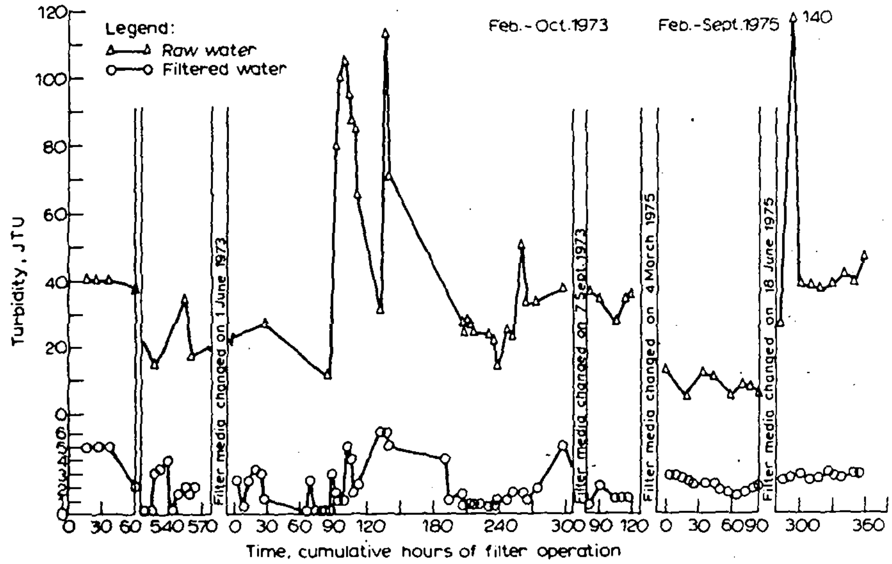

Fig. 1. Efficiency of pilot water filter to remove turbidity (JTU), Ban Som, Changwat Korat, Thailand.

TABLE II

Bacterial removals of the two-stage filter unit at Ban Som, Thailand

	Bacteria	
	coliforms	fecal coliforms
Raw water, range (MPN per 100 ml)	400—11,000	23—≥ 2,400
Average value (MPN per 100 ml)	3,290	675
Filtered water, range (MPN per 100 ml)	20—2,400	≤3—≥ 2,400
Average value (MPN per 100 ml)	1,340	280
Percent removal	60	63
Deviation (MPN per 100 ml)	2,240	640
95% confidence internal	730—1,950	106—450
Number of samples	52	52

MPN = most probable number.

The bacteriological removals for the filter covering the seven months of 1975 are represented in Table II. Bacteriological removals for this installation were similar to what is achieved through rapid sand filter plants, but not equal to removals achieved by well-operated slow sand filters; hence further disinfection is required if international standards are to be met. However, the degree of purification achieved represented a large improvement at low cost. The effluent was sparkling clear and free of objectionable tastes, odor or color during the complete test period. Operation cost for the entire village averaged only US \$45.00 per month or \$0.30 per family per month. This included fuel costs, medium replacement, equipment maintenance, and salary for a half-time operator. The filter was in operation only 3—4 hours per day. Output could thus be doubled at minimal marginal cost.

Ban Nong Suang, Thailand

The filter unit at Ban Nong Suang was operated as an "improved contact filtration" unit. This water was particularly difficult to treat and would normally not be treated by filtration alone. Raw-water turbidity ranged from 300 to 600 JTU, and the coagulant demand was from 180 to 280 $mg\,l^{-1}$. Even with proper alum flocculation, the resulting floc settled very slowly requiring ~6 hr. to produce a clear supernatant. The villagers utilized the treated water for drinking and cooking because it was their only available supply during the dry season. In the filter plant, alum was added to the raw water at the intake side of the raw-water pump, at a dosage of 100—200 $mg\,l^{-1}$. A three-stage filter unit was then tested comprising two stages of fiber plus one of burnt rice husks. The rapidly mixed water plus alum flowed into the first-stage jar of coconut fiber where it filtered at a slower than normal rate of 0.6 $m^3\,m^{-2}\,hr.^{-1}$. The effluent turbidity from the first-stage coconut fiber filter was reduced to the 10—50-JTU range by the second-stage coconut fiber filter. Finally, the third-stage burnt rice husks reduced the turbidity to less than 5 JTU in the final effluent through much of the filter run. Thus the two stages of coconut fibers greatly reduced the turbidity load on the third-stage filter which resulted in a significant increase in the duration of the filter runs to over 75 hr. of operation per run, after which a substantial increase in effluent turbidity occurred. Bacteriological removals were significantly improved using the three stages also. Coliforms were 80—90% removed by the first two stages. The average overall removal by all three stages was higher than 95% (SEATEC, 1975). Results of a typical filter run are shown in Fig. 2.

Nong Khaem, Thailand

The unit at Nong Khaem draws its water from a tributary canal of the Chao Phya River. The filter operated between 6 and 10 hr. per day serving a large orchid farm of over 500,000 potted orchid plants covering 4 ha. The orchid plants require a turbidity-free water that has not been treated with chemicals. The coconut fiber-burnt rice husks filter appeared ideal for treatment of the turbid river water. The filtered water was used also for domestic purposes by the caretakers and workers living on the farm. Results of operations in 1973 and 1975 are presented in Fig. 3 showing turbidity removal. The media were replaced every 4—5 months only. Bacteria removals over the study period averaged over 90%, but effluent values were erratic, particularly during the last three months of the 1975 study. One some days the effluent

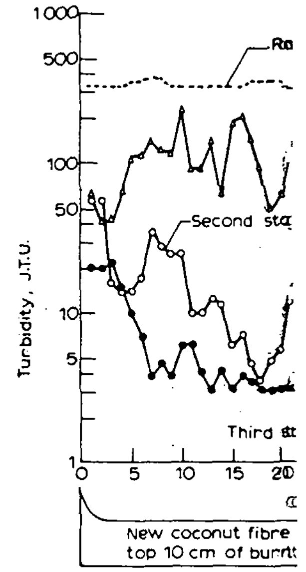

Fig. 2. Removal of turbidi

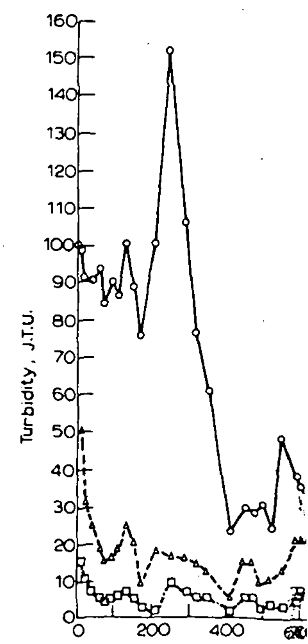

Fig. 3. Filter performance

ır the entire village
ℒ per month. This
maintenance, and
ı only 3—4 hours
'cost.

'improved contact
ɔ treat and would
ɔidity ranged from
;80 to 280 $mg\,l^{-1}$.
ettled very slowly
ägers utilized the
eir only available
ɛ added to the raw
dosage of 100—
prising two stages
ś water plus alum
ltered at a slower
ty from the first-
ʼU range by the
ɛ burnt rice husks
ent through much
eatly reduced the
ignificant increase
ion per run, after
ed. Bacteriological
s also. Coliforms
ɛ overall removal
75). Results of a

itary canal of the
ɛ per day serving
overing 4 ha. The
een treated with
d ideal for treat-
also for domestic
Results of opera-
arbidity removal.
removals over the
eatic, particularly
days the effluent

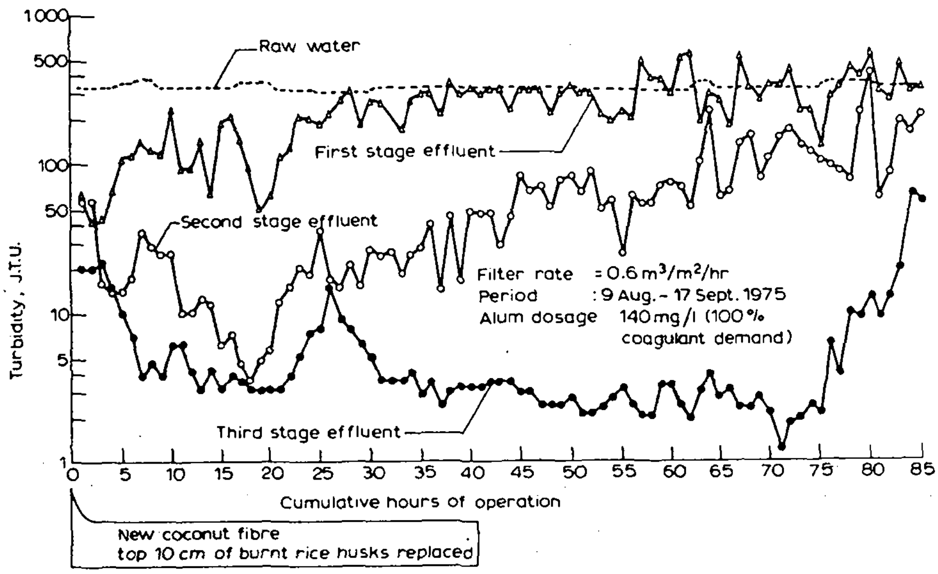

Fig. 2. Removal of turbidity using three-stage filter unit at Ban Nong Suang, Thailand.

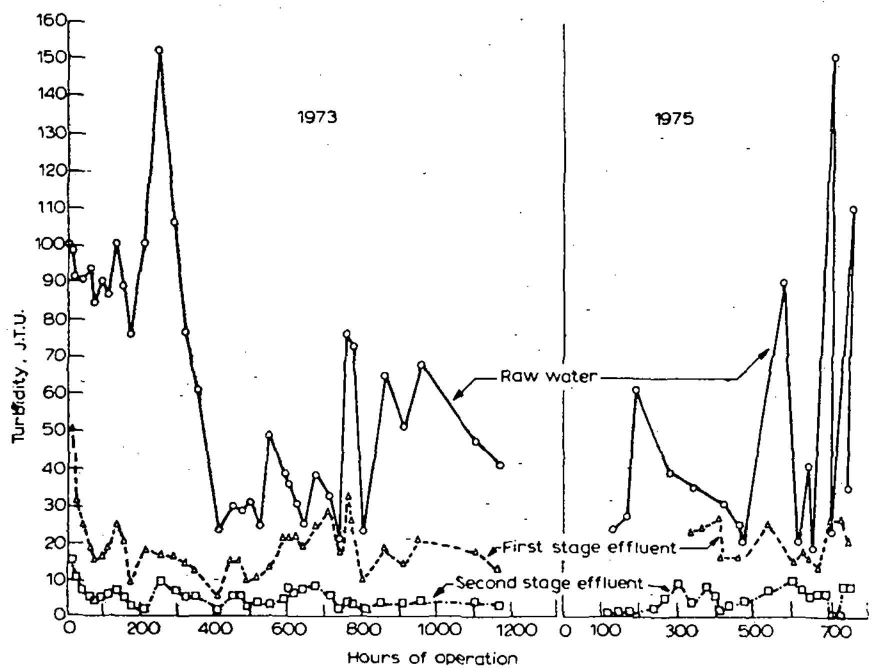

Fig. 3. Filter performance on turbidity removal pilot unit at Ban Nong Khaem, Thailand.

showed zero coliforms (100% removal) and on other days zero percent removal. It was believed that bacteria trapped in the media were periodically loosened and discharged with the effluent causing the erratic results.

Balagbag, Milaor, Philippines

The filter unit at Balagbag, which serves a barrio (community) of about 60 families was completed in 1976. The unit draws its water from a surface stream which passes alongside the project property. Water was pumped by a gasoline-operated pump to the upper filter tank then passes by gravity through the two filters in series to a large 6-m^3 concrete storage tank. Chlorine was added when available to the storage tank for disinfection of the water supply. Water-quality data of the raw water, treated water, and the alternative ground-water supply (obtained by residents using hand-pumps installed in shallow wells) are shown in Fig. 4 for iron removal (SEATEC International, 1977). Effluent turbidity was generally less than 5 JTU, and iron less than 0.6 mg l^{-1}, both significantly better than the local groundwater. Bacteriological data, based on six samples only, showed an average 87% removal by the filter with a residual bacteria count prior to chlorination similar to that of the alternative groundwater.

The residents families of the barrio who previously spent an average of 40 hr. per week per family fetching water from the district municipality and paying over US $1.65 per 1000 l ($6.30 per 1000 gal.) for it, were enthusiastically utilizing the filtered water for drinking and cooking. They voluntarily paid to the barrio captain US $0.15 per family per month to operate the system. This was sufficient money to pay for gasoline costs and pump repairs. The barrio captain spent 3—4 hr. per day "free" to operate the filter system.

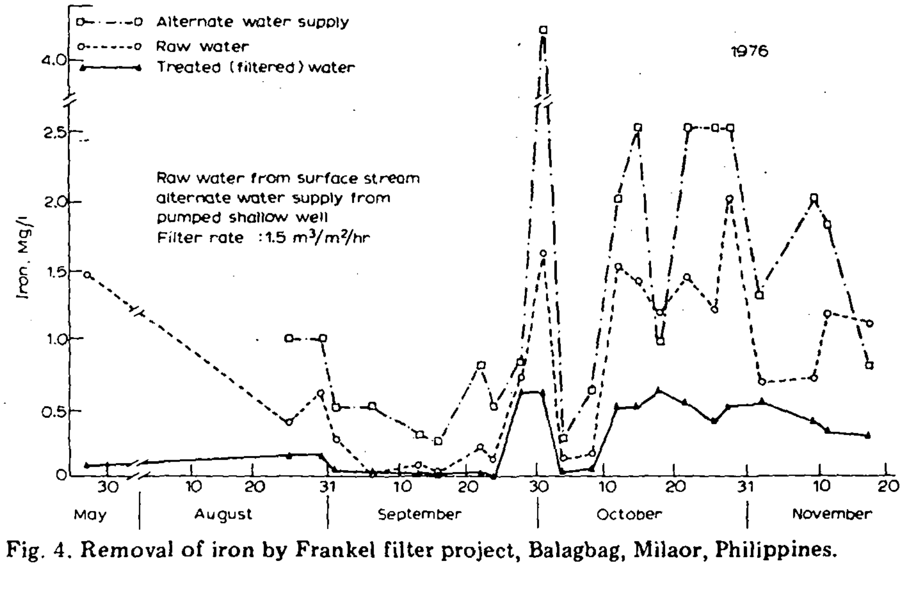

Fig. 4. Removal of iron by Frankel filter project, Balagbag, Milaor, Philippines.

San Francisco, Cana

The unit at San F
well whose quality
came from this well
and brought in by
purposes. About 30–
from the filter was
the iron level from
the filtered water.

Operation of the
maintenance of the
resident participatio
accepted by the resi
Francisco and a thi
Bicol region are bei
sizeable savings in
pump more than off
izing the community
smaller filter units a
range of 30—60 famil
be reduced to ~US $

CONCLUSIONS

Since the presentat
of the coconut fiber—
of field installations.
the main parameters,
ing results equal to sl
particulates including
to no treatment. The
fact that the two-stag
the case for Southe
relatively low raw-wat
~ 10 times higher filt
significant absorption
by use of additional
desired. It is believed
represents a reasonab
more expensive water
filtration) simply cann
simple first-stage inves
water-supply—sanitatio

San Francisco, Canaman, Philippines

The unit at San Francisco draws its water from a large-community shallow well whose quality is turbid and high in iron content. Water supply generally came from this well or was likewise purchased from the district municipality and brought in by boat. The Bicol River was used for washing and bathing purposes. About 30–40 families participated in the project. Effluent quality from the filter was ~5 JTU. Iron removals were most pronounced reducing the iron level from $50\,\mathrm{mg\,l^{-1}}$ in the ground water to less than $0.2\,\mathrm{mg\,l^{-1}}$ in the filtered water.

Operation of the units in the Philippines was dependent upon proper maintenance of the gasoline-operated pump. When the pump functioned, resident participation was high and the quality of water was enthusiastically accepted by the residents. However, pump problems were frequent in San Francisco and a third location San Juan. Therefore newer projects in the Bicol region are being initially started utilizing a hand-operated pump. The sizeable savings in both capital and operating costs associated with a hand-pump more than off-set the added administrative burden needed for organizing the community residents to share in the pumping load. By starting with smaller filter units and using hand-pumps to serve villages in the population range of 30–60 families (200–300 persons) per filter unit, capital costs will be reduced to ~US $2.00 per capita.

CONCLUSIONS

Since the presentation of the laboratory results in 1972, continuous testing of the coconut fiber—burnt rice husks filter has been carried out at a number of field installations. The accumulated data, using turbidity and coliforms as the main parameters, show that this type of two-stage filter, while not achieving results equal to slow sand filtration, does achieve significant removals of particulates including bacteria to produce an effluent of quality far superior to no treatment. The major difference between the two approaches is the fact that the two-stage process can handle waters of high turbidity (usually the case for Southeast Asia), whereas the slow sand filter is limited to relatively low raw-water turbidities. Also, the two-stage process operates at ~10 times higher filtration rates than the slow sand filter, and incorporates significant absorption capability for removing tastes and color. Moreover, by use of additional stages higher levels of removals can be achieved if desired. It is believed the quality of effluent from the two-stage process represents a reasonably good quality for most villages where investment in more expensive water-treatment plants (rapid sand filtration or slow sand filtration) simply cannot be afforded. The two-stage filter also serves as a simple first-stage investment in a multi-stage development process to improve water-supply—sanitation services in rural areas.

ACKNOWLEDGEMENTS

The filter plant installations described in this paper were financed primarily from funds received through research contracts with the U.S. Agency for International Development (U.S.A.I.D.). The filter plants to the Mekong Committee, U.N. Economic Commission for Asia and the Far East (E.C.A.F.E.), and the Asian Institute of Technology (A.I.T.) when the author was an Associate Professor at the Institute. The filter studies have been continued through a contract between U.S.A.I.D. and SEATEC. The filter plant at Nong Khaem, Thailand, was initially financed by A.I.T., and has been operated since by its owner. The Philippines projects were financed jointly by U.S.A.I.D. and the Bicol River Basin Development Program, Naga City. The author gratefully acknowledges the financial, administrative and technical support provided by these organizations.

In addition, the author received in 1973 the Annual Environmental Protection Award from the Stenberg—Flygt Corporation of Sweden for development of the coconut fiber—burnt rice husks filter. This award enabled the author to travel and present findings from the studies to many individuals and organizations around the world resulting in worthwhile feedback and professional encouragement for the research still underway. The author is indebted to Stenberg—Flygt Corporation for their recognition and generous award.

Lastly, the author is particularly grateful to his colleague Dr. Harvey F. Ludwig for his many invaluable suggestions, advice, and constructive criticisms.

REFERENCES

Frankel, R.J., 1974. Evaluation of pilot water treatment units using inexpensive local materials as filter media for supplying drinking water to rural communities in the Lower Mekong Basin countries. Asian. Inst. Technol. (A.I.T.), Bangkok.

Frankel, R.J. and Sevilla, A.S., 1973. An Asian technological approach to water reuse; series infiltration using local filter media. 6th Int. Conf. on Advances in Water Pollution Research, Int. Assoc. Water Pollut. Res. (I.A.W.P.R.), Jerusalem.

SEATEC (Southeast Asia Technology Co., Ltd.), 1975. Development and field testing of the coconut fiber/burnt rice husk filter for supplying drinking water to rural communities in Southeast Asia., Phase II. U.S. Agency Int. Develop. (U.S.A.I.D.), Bangkok, Contract No. AID 490-25.

SEATEC International, 1977. Evaluation of the rural water supply project using the coconut fiber/burnt rice husks ("Frankel filter") in the Bicol river basin, Philippines. U.S. Agency Int. Develop. (U.S.A.I.D.), Manila, Contract No. AID 492-1203.

Journal of Hydrology,
Elsevier Scientific Pub

STUDIES FOR AB
SEWER OVERFL

P.E. WISNER[1], W.G.C
[1] *Water Resources Divi*
[2] *Eldorado Nuclear Lin*

(Accepted for publica

ABSTRACT

Wisner, P.E., Clarke,
from combined sew
Survival. J. Hydrol.,

A methodology wit
puter models is discuss
the Lumped Quality M
runoff models to asses
sewer overflows are des

INTRODUCTION

At present about
combined sewer sy
in spite of dilution
chemical oxygen de
may be greater tha
not only wash poll
also flush out depo
sludge often accum
to be flushed out du
stream or lake into

In Canada, the a
waters have resulted
be installed in new
years (W.R.E.—H.E
from separate storm
dition of sanitary
usually high in susp
centrations approac

* Formerly with James