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9. ABSTRACT

This report presents the results of field tests of a simple, inexpensive, and efficient method of water treatment for rural communities in Southeast Asia. The method consists of filtering stream or pond water through 80 cm of shredded coconut fiber and then through 80 cm of burnt rice husks. The coconut fiber reduces turbidity and removes suspended solids, while the rice husks achieve the second or polishing stage in turbidity and remove bacteria. The burnt rice husks also remove taste, color, and odor through the process of adsorption. The method was developed in two years of laboratory research at the Asian Institute of Technology, Bangkok. Pilot-plant testing of the new two-stage system began in 1973 under a research contract with UN/ECAFE, with financial assistance from USAID, in Thailand, Cambodia, Vietnam, and Laos, but was continued in 1974 only in Thailand because of insecure conditions in the other countries. This report on Phase II of the research presents the results of a study of pilot plant operations in Ban Som and Ban Nong, Thailand, villages of 800 and 5,000 persons, from February through October, 1975. Also reported on is a field test of an individual-family-sized filter employing a single-jar dual-media unit. Among the research findings: Several filters operated successfully for nine months with minimum supervision of the village operators. Filter media were changed only twice in the nine-month period. The filters are capable of treating most surface waters successfully without the need for chemicals, except for waters with abnormally high colloidal turbidities. But those waters can be treated by the filter by adding coagulant chemicals to the raw water. The bacteria removals achieved averaged 76 to 86 percent, although the removals varied considerably; individual grab samples varied from 30 to 100 percent removal. Effluent quality was particularly erratic during the first ten days after media changes, prior to the build-up of a biological layer on the surface of the media. In all cases disinfection of the final effluent would

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be necessary to meet recommended international bacteriological standards. The filter is less efficient at removing bacteria than is slow sand filtration (which generally removes 98-99 percent bacteria), but it is ten times faster, and slow sand filters cannot effectively handle the high-turbidity waters in Southeast Asia without preliminary treatment by either chemical coagulation and sedimentation or roughing filters. The quality of the treated water physically was good; it was generally sparkling clear, with a turbidity of less than 5 JTU, and it was colorless, odorless, and without any noticeable taste. In general, treated water met WHO international standards for clarity, taste, odor, and color, although a disinfectant such as chlorine needs to be used to reduce the coliform densities to the usual standards (1 coliform per 100 ml in the U.S.). Future research recommended includes continuation of the pilot plant study at Ban Nong, field testing of simple chlorinator at both villages, analyses of the filter materials, continued field testing of the jar filters, introduction of hand and/or bicycle pumps (instead of gasolene-powered) and recording of villager reactions, and definition of extended research involving 20 villages over a ten-year period.

PN-AAB-945

DEVELOPMENT AND FIELD TESTING

OF THE

COCONUT FIBER/BURNT RICE HUSK FILTER

FOR SUPPLYING DRINKING WATER TO RURAL COMMUNITIES IN SOUTHEAST ASIA

PHASE II

FINAL REPORT

DECEMBER 1975

TO

OFFICE OF REGIONAL ECONOMIC DEVELOPMENT AFFAIRS (RED)

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DEVELOPMENT AND FIELD TESTING OF THE COCONUT FIBER/BURNT RICE HUSK FILTER

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DEVELOPMENT AND FIELD TESTING OF THE COCONUT FIBER/BURNT RICE HUSK FILTER

I. INTRODUCTION

A. Background

The development of the coconut fiber/burnt rice husks filter was a result of some two years of laboratory research at the Asian Institute of Technology, Bangkok, in a search to find a simple, inexpensive, and efficient method of water treatment for rural communities in Southeast Asia. The emphasis of the research was to utilize local materials as filter media, in a gravity fed system without the need for backwashing, and to eliminate wherever possible the use of any chemicals.

The methodology developed was a two-stage filtering process using coconut fiber and burnt rice husks. The raw water from a surface stream, pond or shallow well, was first passed through shredded coconut fiber, which achieved an initial reduction in turbidity and suspended solids removal, then passed through burnt rice husks, which achieved the second or polishing stage in turbidity and bacteria removals. Generally no chemicals were needed, but in certain cases some coagulants might be needed to enhance removals of colloidal materials by the coconut fiber. The first stage filter with coconut fiber acted as a substitute for the coagulation and sedimentation phases of conventional water treatment plants. The second stage, using burnt rice husks to remove residual turbidity and bacteria, was similar to the rapid sand or slow sand filtration phase of conventional water treatment plants. However, in addition to achieving removals by the process of filtration, the burnt rice husks appeared to achieve some additional removals of taste, color, and odor through the process of adsorption, similar to the use of activated carbon.

Pilot plant testing of the new two-stage filtration system began in 1973 under a research contract from the Committee for the Coordination of Investigation of the Lower Mekong Basin, UN/ECAFE, with financial assistance from the Office of Regional Economic Development, USAID. The

pilot project built two units in Thailand, one in Cambodia, one in Vietnam, and began a unit in Laos. 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. The project was carried out for one year under the contract and the pilot plants were then turned over to the villages to operate themselves.

In Thailand, both villages continued operation of the pilot plants in 1974. At Ban Som, a village of approximately 800 persons, the village headman continued operation of the system by collecting ฿ 0.5 per household member per month. However, this lasted only about three months as the raw water source almost dried up. Because the amounts of water produced were not sufficient, numerous families stopped paying their monthly water fees, and finally insufficient funds to pay the village headman a salary (who was also operator of the system) resulted in shutdown of the project. On occasions the village Wat (Buddhist Temple) operated the filter for its own water use with the Wat paying for the gasoline to run the pump. Heavy rainfall in the wet season of 1974 filled the stream and low areas of the village to very high water levels prior to the reopening of the filter project in February 1975.

In Ban Nong Suang, a village of almost 5,000 persons, the village headman continued operating the pilot project by using an appointed operator throughout the entire year prior to the beginning of this study. In that period the headman collected money from the villagers who used the treated water. The village became split in opinion on support of the village headman to continue operation of the filter project. Of a total population of about 5,000 villagers, less than 1,000 continued to support the project primarily because of insufficient treated water and inconvenience in getting water from the one central location. During the rainy season, output was further reduced and the plant was often shut down for several days or weeks. The village headman claims to have paid for the balance of operating costs each month when insufficient funds were collected from the villagers. However, the operator stated that he was

not paid for his job and finally quit during the rainy season of 1974. Additional information on the villages and previous operating results are available in past project reports (Ref. 1).

In Cambodia, Vietnam, and in Laos conditions of insecurity prevented continuation of the pilot projects under this study.

B. Pilot Plant Testing Phase II Objectives and Scope

The previous and proposed programs of research for development and eventual future full scale utilization of the two-stage water filter are delineated in Figure 1. The first pilot project carried out under the auspices of the Mekong Committee is referred to as Phase I of the pilot plant testing program as shown in Figure 1. This study, carried out under a direct contract with USAID, is referred to as Phase II.

The primary objective of the Phase II pilot plant research project was to study the bacteriological removal efficiencies of the filters under all operating conditions and to present reliable statistical data of such removals covering a period of at least nine months of pilot plant operation. Such data are presented for both Ban Som and Ban Nong Suang from February through October 1975. A second pilot plant of the smaller 1.25 m^3/hr size was built at Ban Nong Suang in March and started operation on 2 April 1975. Also in April the filter unit at Nong Khaem, used to produce water for orchid farming and domestic purposes, was brought within the scope of the project. These two additional pilot units were substituted for the village units in Laos and in South Vietnam which were included in the original scope of study of the Phase II project, but which were unfortunately inaccessible due to conditions of insecurity in both countries.

A secondary objective was to develop and field test an individual family-size filter for both turbidity and bacteria removals. A single jar dual-media unit was designed and tested in conjunction with a coconut shell chlorinator, the entire unit representing a very economical design.

Offices and laboratories were operated both in Bangkok and in Korat at approximately the mid-point location between Ban Som and Ban Nong Suang.

Each laboratory and office was staffed by a full-time biologist/chemist, an engineer, and two assistants for sample collection and laboratory work. The laboratory in Korat was furnished with equipment supplied by project funds and some borrowed from the Provincial Headquarters of the Rural Water Supply Project, Ministry of Health, Thailand.

II. PILOT FILTER UNITS CONSTRUCTED AND OPERATED UNDER THE PROJECT

A. Ban Som, Korat Province

The unit at Ban Som is a small two-stage filter consisting of two large ferro-cement jars used in series to treat raw water from the village stream. The filter jars are mounted on top of nine circular storage tanks built by the Ministry of Health to store the treated water (or rain water which was to be collected from the roof of the village temple). A sketch of the pilot unit is shown in Figure 2 and a photograph of the completed unit is shown in Figure 3. Each water filter jar is 1.4 meters diameter at the widest point and 1.3 meters high. The maximum surface area is 1.5 m^2 and the filter media are 0.6-0.8 meter deep. Using a filtration rate of between 1.0 and 1.25 m^3/hr, a maximum of 2 m^3 (2,000 liters) of filtered water can be produced per hour when the filter media are new. Through daily use of the filter, the media begin to clog causing a gradual build-up in the head loss through the filter, which causes the flow to decrease. At a head loss of about 1.0 meter the flow drops to about 50 percent of the design value (0.5-0.6 $m^3/m^2/hr$). At this time, the media were removed and discarded, and new media were placed back in the filter jars. The coconut fiber is generally washed in the raw water stream to remove the mud caked solids, and then returned to the filter jar for reuse. The top layer of 10-15 centimeters depth of burnt rice husks is scrapped off and removed and a new layer added at the time of changing the media. During Phase I operations the media were changed three times during 1973 (filter runs lasted between 300 and 570 hours of operation per run). In Phase II operations, the media were changed twice during the nine months of operation (filter runs of 140 to 660 hours of operation per run).

The operator of the pilot unit is the village headman who volunteered himself to maintain and operate the filter unit and take responsibility for collecting fees from the villagers, purchasing the gasoline for running the pump, and caring for the unit and its upkeep. He received ฿ 300 and ฿ 200 per month salary for this work under the Phase I and Phase II projects, respectively. In Phase I, this salary was agreed to as a minimum by the village headman and representatives from the Ministry of Health. During

both phases salary and operating costs were paid for from project funds. Funds collected from the villagers during the interim year (104 families) however were insufficient to maintain the salary. When most of the collected water fees went into purchases of gasoline for the pump, the village headman cut back on the number of hours of filter operation per day (originally 4-5 hours only) to 2 hours in the late afternoon before sunset. The villagers complained of insufficient water, refused to pay their water fees, and after three months of conflict the plant was closed. The village headman also had to spend two hours on a local bus for each trip into town to purchase gasoline in the 20 liter container available for gasoline storage. This amount of gasoline lasted 4-5 days. The trip to purchase gasoline was often delegated to another family member as the village headman had other village responsibilities.

The headman's education included completion of elementary school (to grade 4 as required by law) and more than ten years experience working as a truck driver. His full-time occupation was as rice farmer. As a village headman, he had received no special training of any kind from the government. He operated the plant with the agreement of a village committee. The filter was the only village sponsored project until June 1975 when the villagers undertook the beginning of construction of their village temple. The temple, which is being built with voluntary labor and donations, is due for completion in 1977.

The filter fee system is based on a uniform pricing policy per family. The village headman collects the money and controls all expenditures. In the event that a family does not make payment on time, the water supply is extended to the family for a period of two months before the headman terminates their use of the filtered water. Assistance to maintain the project is now being saught by the headman from the Provincial Headquarters of the Rural Water Supply Project, Ministry of Health. It is expected that unless the salary of the headman is maintained that he will revert back to less pumping, hence less filtered water available for the villagers, resulting in villager reluctance to pay the water fees, etc.

B. Ban Nong Suang, Korat Province

The unit at Ban Nong Suang, completed under the contract with the Mekong Committee, was a large scale plant originally built to supply the entire village of some 5,000 inhabitants. Extremely fine colloidal material in the raw water necessitated the use of aluminium sulfate (alum) as a coagulant in the first stage filter which was converted to a sedimentation tank followed by filtration in the second stage filter using dual media of coconut fiber and burnt rice husks. The rather poor settling characteristics of the alum flocs in the sedimentation tank necessitated a 4-6 hour sedimentation period causing the operator to limit the plant's output to two batches of settled water per day of 20 m^3 maximum. The settled water then passed through the second phase dual media filter at a rate of 1.0-1.5 $m^3/m^2/hr$. The final product was distributed to the village from a large storage tank with 22 water taps.

Some 110 families consisting of 746 persons utilize the filtered water for domestic purposes on a more or less continuous basis and contribute funds to the village headman to keep the plant functioning. Project funds were used to supplement the amount collected to permit proper addition of coagulant and to guarantee salary payment of ฿ 500 per month for a full-time operator who lived at the site of the plant.

In order not to disturb the limited water supply furnished to the village by the large scale pilot plant, a second small pilot plant was constructed using two stages, with coconut fiber in the first filter jar followed by burnt rice husks in the second jar. Raw water, pumped from the earthen lined reservoir of some 5,000 m^2 surface area, was fed to both water treatment units simultaneously. Alum is added to the raw water at the intake side of the pump and is mixed thoroughly by turbulence within the 4 inch diameter pipeline along the 100 meter route to the sedimentation tank of the large unit and to the first stage filter of the small pilot unit. A photograph of the two pilot plants, built side-by-side, is shown in Figure 4.

Addition of alum to the raw water increases the particle size through coagulation of the colloidal size material permitting "improved

contact filtration" with the coconut fiber. Since coconut fiber does not have a small effective diameter similar to sand, burnt rice husks or other granular types of media, rapid clogging of the coconut fiber at the surface of the medium was not expected. Rather it was believed that the penetration of the flocs would be throughout the fiber and that the filter depth would permit sufficient contact time to reduce the raw water turbidity to a low enough level so that the second stage burnt rice husks could effectively produce a clear water. It was hoped also that the improved contact filtration rate would increase treated water output while still maintaining an acceptable water quality, and thereby present an alternative to the village headman for increasing water output from the large scale unit. More water would enable the village to serve more families and gain more revenue to operate the system.

The farmers at Ban Nong Suang are tapioca root growers, and utilize the cash value of the crop to purchase their rice, water, and other staples. A good yield and higher tapioca price in 1975 provided higher than normal incomes to most families. Thus the ability and willingness of the villagers to pay for water is good and the headman is anxious to find a way to increase water output.

The operator of the water system at Ban Nong Suang was a previous rice mill employee and was chosen by the village headman to operate the water filters on a full-time basis at ฿ 500 per month. This salary was guaranteed throughout the life of this study and was to be maintained by the village headman if he could obtain sufficient income from the families in the village using the filtered water. The village operated the water system on their own with no aid or assistance from the government. A uniform pricing policy was established by the village headman based on a fee per household regardless of family size and a higher fee for the few stores and restaurants in the village. Only the village temple received water free of charge. In the event a family did not pay the water fee in time, the payment period was extended one month after which time the family could no longer use the community system.

C. Nong Khaem, Thonburi Province

The pilot plant at Nong Khaem is a 1.25 m^3/hr unit similar in design to that at Ban Som. However, the filters are standard size 1 m^3 galvanized iron water storage tanks and the pump is electrically run. The raw water comes from a tributary canal of the Chao Phya River. The unit operates four to six hours per day serving a large orchid farm of some 500,000 potted plants covering ten rai (four acres). Orchids require a turbidity-free water and one that has not been treated with chemicals. Thus the filter effluent offerred an excellent supplementary source of water to the rain water supply which was limited to five months per year.

Farmers utilizing this system previously purchased municipal water by 6-8 m^3 truck load during the dry season rather than use the turbid canal water. The municipal water, which is coagulated with alum and chlorinated prior to distribution, was mixed and stored with existing rainwater prior to usage. The filter effluent at Nong Khaem is also used for domestic purposes by the ten caretakers and family workers. This unit was constructed and utilized as a test pilot plant in 1973 prior to the Phase I construction of pilot plants in the Lower Mekong countries. Operating data are available for over a two-year period.

D. Individual Family-Size Jar Filters, Soi 5, Bangkok

Four standard size (cement made) water jars 60 centimeters high were converted into water filters and tested treating typical surface pond runoff water collected during the wet season. This water is rainwater/drainage which finds its way into an unlined earthen pond during the wet season. Water quality varies throughout the year due to runoff, evaporation changes, and the effects of aquatic life in the pond. The appearance of the water is typically brown in color (much of which is reflected from the earthen sides and bottom of the pond).

The family size filters were constructed as a single container filtration unit with ten centimeters of shredded coconut fiber or a four centimeters thick woven coconut fiber mat on top of 30 centimeters of burnt rice husks. The base of the jar contained a perforated plastic tube $\frac{3}{4}$ inch diameter curved around the bottom of the jar to permit

collection of filtered water from throughout the surface area of the filter. The perforated tube was covered with $\frac{1}{8}$" - $\frac{1}{4}$" diameter pea gravel which prevented the burnt rice husks from entering the tube with the filtered water. The tube was connected to a $\frac{1}{2}$ inch diameter three inches long galvanized iron pipe section cemented into the hole at the bottom of the jar.

Various configurations for water controls were tried with the family-size jar filter in an effort to prevent wastage (e.g. from children's play) and still maintain water levels above the media to prevent drying of the biological layer which forms at the surface. The ordinary tap, while being the easiest to install and operate, had the disadvantages of being left open or leaking and thus caused both wastage and lowering of the water level below the upper surface of the media. A pressure release valve reduced the wastage considerably but did not solve the problem of how to maintain water above the media. A third type of overflow valve was tried where the effluent pipe exited from the filter at the top level of the media (rather than at the bottom). With an air intake tube to break the suction, the effluent flow would stop automatically when the level of water in the filter fell below the top of the media. However, this approach presented problems in cleaning of the media since the water could not be drained except by spilling water from the top, which proved to be both cumbersome and inconvenient. Also the maximum head loss of this design was limited to the vertical distance between the top layer of media and the lip of the jar - only some 20 centimeters in this case. This was believed to be too small a head loss for long filter runs and hence the idea of using the water level control as a design parameter was dropped. The final design used for testing under this program, for both turbidity and bacteriological removals, is shown in Figure 5.

The jar filters were operated twice per day, once in the mornings and once in the late afternoons for a 2-3 hour continuous period throughout the test runs. Originally three filtration rates were tested, namely 1 liter/min, 2 liters/min, and of 4 liters/min. Quality of the effluent was essentially identical for the slower rates and better than that of the highest rate. The highest rate was also difficult to maintain because

it drained the small filter too quickly causing the water level to fall below the filter media. This was undesirable because drying of the upper surface of the media kills the biological layer (or "schmutzdecke") which is valuable in improving bacteriological removals. Hence, a rate of 2 liters/min was chosen for the majority of the runs. This rate was considered sufficiently fast for filling bottles or buckets used for storing drinking and cooking water. A rate of 2 liters/min corresponded to a filtration rate of about 0.8 $m^3/m^2/hr$ of filter surface area.

III. RESULTS OF PILOT PLANT OPERATIONS

A. Ban Som, Korat Province

The unit at Ban Som was operated seven days per week by the village headman from February through the end of October. Personnel from the SEATEC Korat office and laboratory collected daily samples (7 days per week) for bacteriological analysis, except a period of 5 days at the end of each month during which samples were not taken. The unit was operated 2-4 hours per day, once in the early morning and the other in the late afternoon. Two pump breakdowns occurred in the nine month period following the major pump overhaul in February, which further delayed consistent data gathering. The plant was shutdown in May for almost the entire month due to the non-availability of proper spare parts and because of poor repair jobs by local mechanics. A new 3 HP Briggs & Stratton pump was purchased and finally installed in late May. In late September flooding of the pump intake location and pilot plant area shut the unit down for another 15 days. Relocation of the intake area was required before the unit could be restarted.

New media were placed in the filters in February; the burnt rice husks were changed and the coconut fiber rewashed in June; and new coconut fiber was placed in the filter in July. As of the end of October when data gathering terminated, the media were used in the filter for 660 hours of filter operation.

1. Turbidity and Bacteria Removals

Samples were taken daily of raw water, effluent from the first-stage, and effluent from the second-stage, and analyzed for turbidity, coliforms and fecal coliforms (E. Coli). Later in August through October samples were taken 3 times a week and also analyzed for shigella and salmonella in the raw water and in the effluent from the second-stage.

Turbidity removals over the nine month period of study are shown in Figure 6. Raw water turbidity ranged from 10 to 76 JTU (Jackson Turbidity Units). Effluent turbidity was consistently less than 5 JTU.

Bacteria removal, using both the coliform group as a general indicator and specifically E. Coli (fecal coliform), showed erratic results after start-up and change of the media for a period of ten days. This is shown in both Figures 7 and 8. Effluent quality improved thereafter showing an increase in overall removal and more consistent results after the ten days. This was probably due to the build-up of the biological layer on the surface of the media ("schmutzdecke"). The same phenomenon occurred with changes in either medium and was shown using either bacteria indicator.

Raw water bacteria levels ranged from 500 to 24,000 coliforms/100 ml and from 100 to 2,500 fecal coliforms/100 ml. Overall removals for coliforms ranged from >50 percent and up to 98 percent, but the coliform contents in the final effluent were relatively high 90-2,000 MPN/100 ml. In the first sixty days of operation, some samples showed effluent coliforms as high as raw water levels. It is believed that these samples represented poor sampling techniques as both plant operators and SEATEC assistants were getting training on proper sampling methods during this period. Similar results were shown using fecal coliforms. However, erratic removals occurred during the first ten days after medium changing or replacement, also, with some samples containing effluent fecal coliform levels as high as raw water levels. Thereafter, all effluent samples ranged between 0 and 1,000 MPN/100 ml and showed removals of > 50 to 100 percent. Although overall removal of fecal coliforms was generally high, the fecal coliform content in the final effluent was much higher than recommended drinking water standards. Bacterial growths were observed in the coconut fiber as shown by the increase in bacteria level of the first-stage effluent being as high as or higher than the raw water content on several occasions. Practically all bacteria removal was accomplished by the burnt rice husks. However, to meet international standards of coliform levels, chlorination of raw water supplies will be necessary.

Shigella and salmonella bacteria were not observed through three (3) months of sampling twice per week in both raw water and treated effluent. All bacteria removal efficiencies are therefore based on coliform and fecal coliform bacteria.

2. Statistical Analysis of Bacteriological Data and Comparison with International Standards

Given the large number of samples collected and analyzed during the nine month sampling period, statistical analyses of bacteriological data were carried out to determine mean, standard deviation, and 95 percent confidence interval. Statistical significance tests were also made to determine whether or not at a 95 percent confidence level the bacteria removals were significantly different for an increase in the filtration rate which occurred for 35 days in June-July after the prolonged shut down. The results of the statistical analyses using all data are shown in Table 1.

The statistical studies show that in actual operation in the field considering all erratic results during start-up periods (and the problems associated with sample collection as mentioned previously) the average overall removal of both coliform bacteria and fecal coliform (E. Coli) was 62-66 percent. Average effluent bacteria levels were for coliforms 960 MPN/100 ml and for fecal coliforms 270 MPN/100 ml. These values were not significantly different at the higher filtration rate (although Table 2 shows better removals 71-78 percent during the period of time).

In Table 2 the same statistical tests were made using a smaller number of sample points. As noted above effluent values of bacteria showed values higher than influent levels only during the first 60 days of operation and within the first ten days of start-up after every media change. The initial high values were believed due to problems of sampling techniques (and not growth of bacteria within the media), whereas the higher levels occurring during the first ten days after media changes were attributed to the absence of the surface biological layer which develops after "ripening" of the filter thus aiding in bacteria removal. Natural variations in bacteria levels were expected as the analysis technique is a statistic itself (most probable number MPN) and large variations occur because of the nature of grab samples which may or may not include large clumps of bacteria in the sample. If one assumes that bacteria removals of the two-stage filter are consistent and more

reliable after the "ripening" or start-up period of ten days is reached, then the question must be asked, can the treated water be used for domestic purposes with more confidence from the viewpoint of the sanitary engineer or health inspector?

Table 2 shows the results of statistical analyses using the collected data minus those sample points where the effluent levels showed bacteria counts $\geq$ the raw water levels. The mean coliform and fecal coliform levels were 623 and 139 MPN/100 ml respectively showing a 76-82 percent removal during the period of normal filtration rate and 80-82 percent during the high filtration rate. The effluent quality is significantly better with bacteria levels one third to one half of those shown in Table 1. However, the bacteria content is still too high by international standards to permit distribution of the water supply to the villagers without disinfection.

Thus it appears that there is no added health advantage gained by discharging the treated water to waste during the ripening or start-up stage (say ten days). Villager operators would gain little in bacteria quality improvement by such a manoeuvre and would cause more disruption to available water supply than the possible benefits of more consistent bacteria removals.

3. Operation Costs of the Filter Project

During the nine months of operation, total monthly operation and maintenance costs of the unit averaged as follows:

Item	Cost, ฿/month
Gasoline	300
Media replacement	60
Pump repair	100
Operators salary	200
Total	660

One operator (the village headman in this case) took full responsibility for operation and maintenance of the unit (repair of the pump, replacement of the media, purchasing of gasoline, starting and stopping pumping, etc. for seven days per week). Although more than 50 percent of the total families in the village complained that they did not get enough

filtered water for their use, the village headman kept operation hours limited to 2-4 hours per day. This was strickly his choice determined by the availability of his time and the worth of his time. Financial restrictions were not responsible for the few hours of filter use per day during the nine month study period as project funds paid guaranteed his salary and paid for all costs over and above collected funds.

The above monthly costs average ฿6.35 per family per month (104 families in the village). The willingness of the villagers to pay is shown in the village surveys (Section IV) in which 96 percent of the families responded that the present rate is not expensive and that they would be willing to pay ฿5 per family per month. Whether the willingness to pay would be higher if more water were available is not known. However, it should also be noted that the survey was completed at the end of the rainy season (October) in an extremely wet year and when rain water storage is at a maximum.

In comparison the average number of jars per family were 1.5 big jars (capacity 1,000 liters each) and 1.1 small jars (capacity 160 liters each). These jars cost each family on the average about ฿635 (at village cost). Such jars generally last ten years before breakage. Family cash income in Ban Som averaged ฿1,585 per family generally from selling jute, kenaf, and kapok. Some income came from wages earned during the dry season (see Section IV). At such a low level of cash income, how much can a family afford on water fees paid per month? It is believed that the two-stage filter scheme can be self supporting even in villages with cash income as low as Ban Som.

B. Ban Nong Suang, Korat Province

The large scale unit at Ban Nong Suang was operated continuously throughout the project period. Data were collected over a nine month period. The unit was operated as first a sedimentation tank followed by a filter using dual media. Alum was added to the intake side of the pump and mixed thoroughly with the raw water in the pipe prior to reaching the sedimentation tank. The quantity of alum added was judged and changed according to the success of developing a heavy floc in the sedimentation basin. The standard jar test was done monthly to determine theoretical optimum alum dosage, which averaged over 200 mg/l throughout the study

period. No flocculation basin was available; likewise no continuous overflow system was available for collecting the settled water (or supernatant of the sedimentation tank). The first tank was filled with coagulated water and allowed to settle 4-6 hours prior to drawing off the clear supernatant for filtration. This was the manner in which the operator felt he could best handle the treatment unit. Improvements were made to speed up the settling process. This was accomplished by attaching a float to the end of the 2" flexible outlet hose, thereby hanging it about one foot below the water surface at all times. In this manner, the supernatant of the sedimentation tank could be drawn to the filter without the need of waiting until all flocs completely settled to the bottom. Operation was intermittent; two hours in the morning and two hours in the afternoon. The pump capacity was found to be only 5 m^3/hr, which was much lower than the rated capacity of 15 m^3/hr (the pump was only two years old).

The small pilot unit was operated four hours per day by the same operator from the time of completion in early April through the end of October. This unit was operated as an improved contact filtration unit with alum added to the raw water similar to the large scale unit above. The coagulated water was fed directly to the first stage of filtration using coconut fiber followed by a second-stage of burnt rice husks. Later a third-stage was added. The first two stages were coconut fiber followed by one-stage of burnt rice husks. This permitted longer filter runs and provided better water quality as explained below.

Samples were collected daily, except during the last five days of each month, from February through the end of July of the raw, coagulated and filtered waters from the scale large unit and from each stage of the small scale unit and analyzed for turbidity, coliform, and fecal coliform levels. From August through the end of October, samples were taken three days per week and both raw and final filtered waters were analyzed also for shigella and salmonella. Again no shigella nor salmonella were detected in any of the samples. Fecal coliform tests were used exclusively to determine bacteriological removal efficiency as of August. Raw water and filtered water fecal coliform counts were more consistent than the general coliform group.

Turbidity and Bacteria Removals

(a) Large Scale Unit: Turbidity removals over the nine month sampling period were very high and averaged over 95 percent as shown in Figure 9. At jar test "optimum" coagulant dosage (referred to as 100 percent alum dosage), removal of turbidity was consistently high and the turbidity in the final effluent was generally lower than 5 JTU. The filter media helped reduce residual turbidity in the settled water. Alum requirements were high due to the high coagulant demand of the raw water turbidity. The water settled slowly and the supernatant water was treated only twice per day through the filter. If coagulation were utilized without filtration, (a) the rate of water treatment would be lower, and (b) the final turbidity would be greater.

Two experiments were carried out using heavy polymers as coagulant aids. For 100 percent alum dosage + 0.4 mg polymer/l, the efficiency in removing turbidity was about the same as 100 percent alum alone. However, visual observation indicated much faster settling rate of flocs (settling rate of 2 x rate for 100 percent alum). For 75 percent alum dosage + 0.4 mg polymer/l, the final turbidity was generally greater than 10 JTU due to the high turbidity level in the coagulated water (and probably due to non-settleable cooloidal particles left in the coagulated water). Thus addition of a heavy polymer would improve throughout.

Under existing conditions, the rate of water treatment was not high enough, and the quantity of treated water was not sufficient to meet the village's demand of water. Application of a heavy polymer may help alleviate the problem, but more study is needed. Use of the polymer was a totally new concept for the village and it was not recommended at this time.

Throughout the entire nine month period of operation no change was made in the burnt rice husks medium. The coconut fibers were washed once and returned to the filter. By the end of the study, the build up in head loss across the filter still had not adversely affected the flow rate.

Bacteria removals are shown in Figures 10 and 11 for coliform and fecal coliform respectively. Bacteria levels in the final effluent were significantly reduced by both the coagulation and filtration steps. However, the actual number in the final effluent was still much higher than that recommended by international standards. Growths of bacteria in the media were believed to occur because of the number of filter effluent samples with bacteria counts equal to or above those found in the coagulated water. Like at Ban Som, diurnal fluctuation in fecal coliform and coliform contents were observed. On numerous occasions, concentrations of fecal coliform in the finished water were higher than those in the coagulated water. Since these phenomena occurred several times, analytical errors were believed not to be at fault. Though the answer of why this occurrence remains unsolved, it is suspected that there is growth of bacteria in the media. The residual organic material accumulated in the media might have encouraged bacterial growth. The overall removals of fecal coliform were generally high, with the exception of the period between the 30th to the 80th days during which some values were as low as 40 percent. The average removals of over 90 percent were observed for both coliform and fecal coliform. The results were more consistent than those of the Ban Som unit, probably due to the use of alum. As at Ban Som, the contents of coliform and fecal coliform were higher than that recommended for drinking water, in spite the fact that removal efficiencies were very high.

(b) <u>Small Pilot Unit</u>: The unit was so designed that it functioned as an improved contact filter. A portion of alumfed water was diverted from the large-scale unit. The major part of flocs was trapped by coconut fiber and the residual turbidity removed by burnt rice husks. The first period of study involved the selection of optimum applied rate. This was based on the quality of the finished water and the total amount of turbidity removed before the increase in turbidity of the finished water occurred (i.e., each run was continued until the turbidity increased over the selected termination value of 20 JTU). During this period alum was introduced at the 100 percent level, i.e., the optimum amount

determined by the jar test. The study concentrated on the filtration rate that would give the best operating results which were judged in terms of length of the operation before washing or replacing the media, and turbidity and bacteria removal efficiencies.

During this period hourly tests of turbidity were made and every two hours fecal coliform tests were carried out. However, tests for shigella and salmonella were dropped since these bacteria were not detected in the Ban Nong Suang raw water.

(1) At the filtration rate of 4 l/min (or 0.24 $m^3/m^2/hr$), the overall removals of turbidity were quite high during the first 24 hours of operation, after which a jump in turbidity occurred. This is shown in Figure 12. During that period, the overall removal averaged over 95 percent. However, turbidity removals by coconut fiber were normally low and erratic, averaging between 60 to 70 percent. Turbidity of 100-200 JTU was carried over to the burnt rice husks. This heavy turbidity load shortened the useful length of filter operation. However, the coconut fiber did remove a significant portion of the turbidity as well as the solids caused by the addition of alum. The run was continued for 50 hours of operation, but results were erratic.

A second test at this 4 l/min rate gave similar results, with a useful operation length of only 22 hours as shown in Figure 13. This time, turbidity removals by coconut fiber were lower than before, averaging about 60 percent. Again the run was continued through 75 hours of filter operation but results were erratic.

The third test at 4 l/min, shown in Figure 14, gave rather high removal of turbidity by the first stage, averaging higher than 85 percent. At the end of the 24th hour the jump in final effluent turbidity was not yet observed. During this test the average raw water turbidity dropped to approximately 400 JTU - considerably lower than that during the second test (about 570 JTU).

(2) At a flow rate of 10 l/min (or 0.6 $m^3/m^2/hr$), the useful length of filter operation was 22 hours as shown in Figure 15. In this test, turbidity removals by the first-stage were low, averaging slightly over 50 percent. Consequently, the high turbidity loading on the burnt rice husks produced a break through after only 22 hours.

The second test at 10 l/min is shown in Figure 16. Average raw water turbidity decreased to 320 JTU, and required an alum dosage of 125-140 mg/l. The filter run lasted about 41 hours before a substantial increase in final effluent turbidity was observed. Removal of turbidity by the first-stage was generally low.

As compared with the first test, the total turbidity removed during this test was about 7.8 kg as SiO_2 versus about 6.0 kg in the first test. In addition, the weight $Al_2(SO_4)_3$ removed during the two tests was about 1.0 kg and 1.9 kg respectively. The system seemed to function better with lower raw water turbidity.

(3) At flow rate of 14 l/min (or 0.84 $m^3/m^2/hr$), the useful length of operation was only 16 hours, as shown in Figure 17. The efficiency of the first-stage was very low, averaging about 40 percent, as shown in Figure 15. From these tests, it was shown that at the higher applied flow rates the coconut fiber contributed a very high turbidity load to the second-stage burnt rice husks cutting down on the length of filter runs.

(4) To compare the three series of tests mentioned above a curve of turbidity removed versus applied flow rate was prepared. Total turbidity removed, as kg SiO_2, was calculated from the start-up of each test through the end of the useful length of operation.

At the applied rate of 0.24 $m^3/m^2/hr$ (or 4 l/min), total turbidity removed was only 2.87 kg as SiO_2. The total turbidity removed almost doubled at the applied rate of 0.60 $m^3/m^2/hr$ (or 10 l/min), then dropped slightly at the applied rate of

0.84 $m^3/m^2/hr$ (or 14 l/min). Not enough data were available to draw a probable relationship through these points. However, the trend indicated that the unit was most efficient in removing turbidity at the applied rate of 10 l/min, and that an increase in the applied rate beyond 10 l/min might decrease the capacity of the system.

In considering the total amount of water produced before the water quality became unacceptable, a similar conclusion was obtained. The total amounts of water with acceptable quality produced were 5.8 m^3, 13.2 m^3, and 13.4 m^3, at the rates of 4 l/min, 10 l/min, and 14 l/min, respectively. There was an obvious increase in the quantity of acceptable water produced when the rate increased from 4 l/min to 10 l/min, but no significant difference was observed when the flow rate increased to 14 l/min. At the higher flow rates it was believed that the influent disturbed the surface of the media causing channelization.

Channelization through the burnt rice husks was observed a few hours after start-up. After draining the water from the second jar, several holes of size about $\frac{1}{8}$" were noticed on the layer of flocs depositing on the burnt rice husks. This indicated evidence of selective percolation of water through the medium. Towards the end of the test, the holes in the floc layer disappeared, and it was very difficult to detect whether channelization actually occurred.

Finally, it was believed that should the turbidity load in the water fed to the second-stage be decreased, that the useful time of filter operation would be considerably longer. It appeared also that the overall turbidity removal (i.e. effluent quality), from start-up till the end of the filter run, was independent of the applied rate and of the residual turbidity from the first-stage effluent. However, the higher rates produced lower turbidity removals in the first-stage. Thus, the useful length of operation, was dependent upon the applied rate, because the second-stage governed the filter run.

(5) Since it was illustrated that the load of turbidity on the second stage was normally high, efforts were made to reduce it. A second jar with coconut fiber was added to the system, making the series consist of two stages with coconut fiber followed by a final stage with burnt rice husks.

The system worked much better than the two-stage system. The efficiency of the first-stage in removing turbidity was more or less the same as the first-stage of the two-stage system. The first two stages however removed more than 70 percent of the turbidity, and the removal decreased only slightly with cumulative operation period as shown in Figure 18.

During the first 6 hours, the final turbidity was high but decreased to lower than 5 JTU thereafter. With an exception of a short period (hrs 23-30), the final turbidity was below 5 JTU during the 75 hour filter run, after which a substantial increase occurred. The burnt rice husks worked satisfactorily as long as they were fed with a water of turbidity less than 100 JTU. With this three-stage system the length of the filter run was about twice the run of the two-stage system. Total turbidity removed was about 15.8 kg of SiO_2 (plus 6.3 kg of $Al_2(SO_4)_3$).

It was believed at the end of the run that if the coconut fiber were washed and the top 10-cm of burnt rice husks replaced, the performance of the filter could be repeated at the same overall efficiency level.

(6) A final test run using the three-stage filter configuration was carried out at a filtration rate of 0.6 $m^3/m^2/hr$ and an alum dosage of about 75 percent, or 105 mg/l, + 0.4 mg Polymer/l. The results are shown in Figure 19. Removal of turbidity by coconut fiber was very low, and overall removal was only about 60-70 percent. The final turbidity was generally high (60-80 JTU) during the first 20 hours, but steadily dropped thereafter. Although there was a trend of decreasing final turbidity with time (to lower than 10 JTU), reduction of the alum dosage to 75 percent of jar test

requirements resulted in poor effluent quality. This was true for both the small and large pilot units. If the alum dosage of about 80-85 percent were used, the results might have been better; however, further study is required before recommendations can be made concerning alum savings.

(7) At the rate of 0.60 $m^3/m^2/hr$ and an alum dosage of 100 percent + 0.4 mg/l of polymer, the three-stage unit showed about 80-90 percent removal of fecal coliforms by the first two stages as shown in Figure 20. The average overall removal for all three stages was higher than 95 percent, the maximum being greater than 99 percent. During the 35th to 75th hours, the final effluent fecal coliform contents were quite low, generally lower than 10 MPN/100 ml and the minimum being 3 MPN/100 ml. The results during this period of test were quite satisfactory.

2. Statistical Analysis

Statistical tests for both coliforms and fecal coliforms were made to determine mean, standard deviation, and 95 percent confidence interval. The results are shown in Tables 3 and 4 for the larger pilot unit at Ban Nong Suang. From Table 4 the mean coliform levels in coagulated water and finished water were 1,690 and 953 MPN/100 ml respectively showing 80 and 85 percent removals respectively. Statistical inference showed that coliform content in the finished water was significantly lower. For fecal coliform, the mean values in the coagulated water and finished water were 129 and 115 MPN/100 ml, with the respective removals of 88 and 86 percent. Statistically, the filter did not improve the bacteria content of the water.

No statistical analyses were made of fecal coliform removals for the experimental two- and three-stage improved contact filter.

3. Comparison of Large Scale Sedimentation/Dual Media Filtration Unit with Small Scale Improved Contact Multi-Stage Filter Unit

(a) System: For the large scale unit at Ban Nong Suang, the storage tank contributed in part to the inadequacy of the system. The tank was installed at the same level as the filter. Thus, the upper part of the storage tank could not be used for storing water at all. For the small scale unit, the filter tanks were elevated to supply the required head between the last stage and the storage tank (only a few centimeters greater than the height of the jar itself). Storage is handled by adding as many jars as needed to meet the demand for treated water.

Considering the installation of the unit, the large scale filter is much more difficult to construct because it must be made of reinforced concrete with adequate foundations. The small scale unit can be installed on an easily-erected and inexpensive platform without the need of piling. The jars are normally available in the villages or nearby markets. Villagers can install the units themselves with a minimal need of engineering background.

(b) Amount of Water Produced: Comparison of the two types of filter units is summarized in Table 5. Under present operating conditions, the filtration rates of the large scale and small scale units were 0.5 $m^3/m^2/hr$ and 0.6 $m^3/m^2/hr$, respectively. The available surface areas were 10 m^2, 1.0 m^2, and 1.5 m^2 for the large scale, two-stage, and three-stage units.

Due to the fact that coagulated water settled very slowly, the large scale unit could treat water only twice a day, with the maximum production rate of 20 m^3/day. There were several complaints about the inadequacy of treated water, particularly in the dry season. The small scale unit of one tenth the surface area could produce 6 m^3 of water per day. For example, two to three small scale filter units could be installed for the same pump capacity of 5 m^3/hr capacity and produce the same output at the large unit if the system were operated at least 10 hours per day.

(c) Length of Filter Run: During the nine month operation period of the large scale unit, the media were changed twice (coconut fiber washed and reused and the top 10 cm of burnt rice husks replaced). The filter unit was operated 4 hours per day at an average rate of 5 m^3/hr and was shut down about five days per month. Therefore, the average filter run of the large unit was 450 hours, and the total amount of water produced was 2,250 m^3/run.

For the two-stage small scale unit, the average filter run was 31 hours, and water production was 186 m^3/10 m^2 media surface/run. Thus, the ratio of water production per run for the large scale and small scale units was about 12:1. With the three-stage small scale filter, the average filter run was about 75 hours and the amount of water produced was 300 m^3/10 m^2/per run. Thus the frequency of washing or replacing the media would be 7.5 times that of the large scale filter.

The turbidity level in the feed to the large scale filter was only about 5 percent of the raw water turbidity while the level was 100 percent turbidity plus alum in the feed to the small scale filters. Therefore, although the amount of water produced by the small scale units was much less than the large scale unit, the total amount of turbidity removed by the small scale units was greater. For the same amount of water produced, the two-stage and three-stage units removed respectively 1.5 times and 2.5 times as much turbidity as the amount removed by the large scale unit.

(d) Costs of Construction and Operation: For comparative purposes, a daily water demand of 20 m^3/day was taken as the basic requirement. The large scale unit would be operated 14 hours per day with pumping and filtration for four hours at a rate of 5 m^3/hr and settling for ten hours per day. One small scale unit can provide water at a rate of 0.6 m^3/hr or 8.4 m^3 in 14 hours. If the small scale unit were operated 14 hours/day, a total of 20/14 or 2 units would be needed.

The following assumptions and cost factors applicable to rural construction are provided to complete the comparison:

(1) For a three-stage small scale unit, two storage jars of 1,000 l capacity are provided (i.e., 5 jars/unit).

(2) Construction of the small scale unit requires a platform structure costing ฿2,000/platform and labor costs at ฿1,000/unit.

(3) Jar cost is ฿400 per jar.

(4) Construction cost of reinforced concrete tanks = ฿950/m^3 of volume (there are three 30 m^3 concrete tanks for the large scale unit).

(5) Pipe work costs ฿115/m for ø 3" GI pipe, ฿75/m for ø 2" GI pipe and ฿40/m for ø 1" GI pipe plus ฿15/m for labor. A total length of 100 m is needed for the intake and 200 m for the filter plus distribution system.

(6) Pump costs for gasoline operated units are ฿5,000 for 3 HP and ฿3,000 for 1.5 HP to handle pump requirements for the large and small scale unit respectively.

(7) Media costs are ฿2 per kg for coconut fiber (1 m^3 volume weighs about 60 kg) and transport costs only for burnt rice husks from local rice mills.

Using these cost factors, the total construction cost of the large scale unit would amount to ฿123,500 and the total cost of the two small scale units to ฿33,500.

For the same amount of treated water, the operating cost of the two small scale units would be somewhat higher. The operating costs are compared as follows:

	Cost, Baht per Month	
	Large Scale Unit	Small Scale Units
Operator's salary	฿500	฿500
Fuel	700	1,000
Alum (coagulant)	500	500
Maintenance	50	100
Media replacement (incl. transport)	negligible	500
Total	฿1,750	฿2,600
Cost ฿/family/month	16	24

The capital costs are considerably lower for small scale units. Several more units could be added at the same total cost and thereby increase the output considerably. The operating costs of the small scale units appear higher because of longer pumping hours and frequent changes in filter media (namely the cost of obtaining the coconut fiber which is assumed replaced monthly). These additional operating costs might be offset by the lower coagulant costs obtainable if the alum dosage can be reduced below the theoretical 100 percent jar test level as noted previously. More research is required on this point. The cost per family per month of ฿16-24 is higher than the present rate of ฿10 per family and ฿20 per store. However, the cost is well within their ability to pay (average annual income of ฿8,520 per year as shown in Section IV).

C. Nong Khaem, Thonburi Province

The unit has operated continuously since 1973 to supply turbid free water for orchid growing. Data were collected three times per week beginning in late April and analyzed for turbidity, coliform bacteria, and fecal coliform removals. As a comparison and a means to expand operation surveillance, data were included covering a 12 month period in 1973-74. Throughout both data collection periods the filter unit has been operated at least two hours per day and often as long as 15 hours per day depending upon water demand and rainfall. The filter effluent was used to supplement stored rain water. Average operation time was six hours per day, and filtration rate 0.5 $m^3/m^2/hr$. The rate was restricted to this value due to the limited pump capacity of 0.5 m^3/hr.

1. Turbidity and Bacteria Removals

Raw water turbidity varied considerably from 10 to 180 JTU and averaged over 5 JTU throughout the study period. Turbidity removals are shown in Figure 21. During the first 90 days effluent quality was continuously less than 10 JTU, but began to increase during the high peak period throughout the rest of the study period and average about 20 JTU in the effluent. Although this level is higher than international drinking water standards, the quality of the effluent was considerably

better than the canal water. The media were not washed or changed even once throughout the study period. The filter media were the same used by the orchid farm since the beginning of 1975. Since April, the media have been used almost 1,200 hours without any attention from the operator. Similar results were reported in 1973-74. Although the filter operated essentially "maintenance free" throughout the year, it is believed that changing the media every 3-4 months would result in better quality effluent by eliminating the short circuiting that inevitably results from such long filter runs.

Bacteria removal over the study period are shown in Figure 22. Removals were consistently high in the first 90 days averaging over 90 percent, but effluent values were also high between 200 and 2,000 MPN/100 ml. From 90 to 135 days, the final effluent was greatly improved with fecal coliforms dropping in the effluent to zero on most days. However a few days of high effluent values indicated that bacteria growths were occurring in both the coconut fiber and burnt rice husks media. Very erratic results continued throughout the remainder of the study period with the effluent showing zero (100 percent removal) on several occasions and 400-2,300 MPN/100 ml (or 0 percent removal) on four occasions. It is believed that bacteria trapped in the media were periodically loosened and discharged with the effluent thus causing the erratic results.

Although no media changes were made throughout the study period, no odor problems occurred with the final effluent.

2. Comparison with Pilot Unit at Ban Som

The raw water from the tributary canal of the Chao Phya River was considerably more polluted than that used for raw water at Ban Som. Coliform and fecal coliforms varied up to 110,000 MPN/100 ml and were never less than 400 MPN/100 ml. Statistically, the efficiency of the two almost identical units can be compared as follows:

	Nong Khaem	Ban Som
Fecal coliforms in raw water, MPN/100 ml	400-110,000	23-2,400
Average	12,060	888
Fecal coliforms in effluent, MPN/100 ml	0-2,800	<3-1,100
Average	851	139
Standard deviation	1,600	229
95% confidence interval of mean	398 to 1,304	74 to 204
Overall average removal, %	77	82

Overall removals appeared lower at Nong Khaem, which was operated every day continuously. The media were not changed throughout the study period and both average removal and 95 percent confidence limit values were inferior to those at Ban Som. In neither case could the effluent meet the international standards for bacteria removal. Operation was simplified and no breakdowns were recorded however due to the availability of electric power to run the pump.

D. Family Size Filters, Soi 5, Bangkok

The final design for individual family size filters utilized a typical chinese style cement made water jar some 60 cm high. Both media were included in the jar: coconut fiber on top, 10 cm deep, and burnt rice husks below 30 cm deep. Water was fed from a surface runoff collection pond and withdrawn from the filter at 1-2 liters per minute (0.25 $m^3/m^2/hr$ to 0.50 $m^3/m^2/hr$) for a 2-3 hour period daily. The unit was operated six days per week. The rate of filtration was more than double that used with slow sand filters.

Water was withdrawn by use of a pressure release valve. The valve was separated from the water jar by a short piece of plastic tubing. This was done to protect the tight fitting of the effluent pipe in the jar. It was believed that the pressure action of the valve would cause the pipe fitting in the bottom of the jar to loosen and thus cause leakage. By inserting a piece of plastic tubing between the pipe and the valve, the

pressure on the valve was not transmitted to the cement binding of the pipe with the thin walls of the jar. Thus leakage or damage to the jar was prevented.

However, the air/liquid interface in the plastic tubing together with the heat and light from the sun, permitted algae growth to occur in the plastic tubing. On two occasions this resulted in odor problems in the effluent water. Both the plastic tubing and the media required changing as a result of the odor build-up.

The steel spring in the pressure release valve also rusted over a 3-4 month period requiring that the springs be changed. Although this design prevented water losses by eliminating the possibility that children left the taps open and would drain the filter dry during off-use hours, the pressure release valve required more maintenance than a simple water tap.

1. Turbidity and Bacteria Removals

Several trial runs were made with the family size filters. These were halted after 30 days to evaluate results and then modify design for improvements. Figures 23 and 24 show typical turbidity removal results for two runs. Turbidity levels in the effluent were generally higher than those experienced at Ban Som but averaged less than 10 JTU. At the two rates of 0.25 and 0.50 $m^3/m^2/hr$, effluent turbidity was about the same.

Bacteria removals for the same runs are shown in Figures 25 and 26. Removals were erratic and generally less than those experienced in the other pilot units because of the shallow depth of media, one filtration stage and hence a shorter detention time. Raw water bacteria content was generally higher than that experienced at the other sites. Average bacteria removals at 1 l/min discharge were 67 and 68 percent, for runs 1 and 2 respectively. At 2 l/min discharge, bacteria removals ranged from 50 to 73 percent for both runs. No significant difference was found between the bacteria removals of the two rates.

For several runs with a woven coconut fiber mat were run in place of loose coconut fiber. The mat, some 5-7 cm thick, is used as a door mat for cleaning one's shoes before entering the house. It was hoped that the mat could be used to compress the burnt rice husks in the

filter thus increasing the density of the media and improving the efficiency of the filter to remove both turbidity and bacteria. The efficiency of the filter with the woven mat did not improve and in fact showed more erratic results. The final effluent turbidity was somewhat higher than with the loose coconut fiber probably due to short circuiting around the edge of the mat. Cutting the rectangular shaped mats to fit the circular shape of the jar was not difficult but a tight fit was not always insured. The results of one run are shown in Figure 27.

2. Effectiveness of Coconut Shell Chlorinator

Because of the generally high levels of coliform bacteria in the effluents from all pilot filters, a simple coconut shell type chlorinator was tested with the family size filter. The original idea came from Malaysia where the unit was tested by the Ministry of Health (Ref. 2). A simple coconut shell as shown in Figure 28 was cleaned and the top cut off for inserting a small plastic bag with lime of chlorine and sand mixture. The mixture is supposed to release enough chlorine over a 20-25 day period to maintain a chlorine residual of 0.1 to 0.2 in the effluent, thereby producing a potable water with only a slight chlorine taste (if any). Three small holes were cut into the coconut shell as described in the unit tested in Malaysia. The unit was tested above the filter media, suspended by a simple stick as shown in Figure 28. This configuration was prefered because the chlorine could be removed by absorption in the burnt rice husks, thus hopefully producing a bacteria free effluent and likewise one free from any chlorine taste.

The results were not completely conclusive but did show the following trends:

(a) Bacteria removals were significantly improved. Removals were erratic however. In Figure 29, the bacteria removals for some 66 days of testing showed that with a chlorine residual of 0.5 mg/l or less in the water above the filter, the effluent still contained high positive bacteria counts. Zero bacteria were recorded less than 30 percent of the time (19 days total). Very little chlorine residual was found in the effluent and on most occasions all the

chlorine was absorbed by the burnt rice husks. Taste of the effluent was excellent and not affected by addition of chlorine above the filter media.

(b) Bacteria removals were more consistent during the period when the chlorine residual in the raw water above the filter was increased to 1.0 mg/l or above (accomplished by increasing the number of holes in the coconut shell from 3 to 6). During those days, zero bacteria in the chlorinated raw water was measured 100 percent of the time, and chlorine residual in the effluent was generally positive but less than 0.5 mg/l. Although the water above the filter showed negative bacteria readings consistently when the chlorine residual was 1.0 mg/l or higher, the effluent from the filter was erratic and showed negative readings only 60 percent of the time.

(c) Bacterial growths in the media were noticed on several occasions, where the chlorinated raw water above the filter showed zero bacteria but the effluent from the filter showed positive readings. These bacteria might have been due to either breaking off of bacteria in the schmutzdecke and their discharge in the filter effluent or bacteria growth in the media.

(d) Control of chlorine residual levels was not easy using the simple coconut chlorinator. Variations occurred daily and control over a general range of values is possible only using this type of chlorinator. Distribution of the chlorine in the filter jar was uneven. The woven coconut fiber met was found damaged directly under the chlorinator by the release of the chlorine of lime directly above the mat. Either the chlorinator must be suspended higher in the jar or the release of the solid lime of chlorine particles prevented by placing a layer of sand in the bottom of the chlorinator. The unit needs further testing and improvements before a final design can be recommended.

Hence, in general, bacteria levels were greatly reduced by the use of a simple coconut chlorinator. Design and use of the chlorinator to insure safe potable water requires further research and

field testing. The concept to chlorinate the effluent from the first stage filter prior to the second stage burnt rice husks will probably produce a potable water free from chlorine residual as well so as not to be rejected by the villagers because of objections to taste.

E. Laboratory Studies on Bacteria Growths Within the Media

Because of the experiences in all pilot filter units where on some occasions higher bacteria levels in the filtered water were recorded than in the raw water, special laboratory studies were conducted to determine whether or not the media were conductive to bacteria growths (that is provided nutrients for the bacteria to grow) or would produce a natural die-away (no nutrients available for bacterial growths).

Three sets of studies were carried out using pond water, tap water from the Bangkok municipality, and sterile distilled water. Both media were tested separately.

1. Coconut Fiber

Pond water from Soi 5 was placed in a filter of coconut fiber medium and coliform bacteria levels were measured over time. The bacteria showed a growth in quantity up to the sixth day when a peak was reached, then natural die-off occurred. On the 29th day, total mortality of the coliform bacteria was observed. Temperature of the pond water was approximately 26-28°C. A similar trend was observed with coconut fiber washed with sterile distilled water prior to the introduction of the pond water. When distilled water was introduced with sterile coconut fiber no bacteria growth was observed. When tap water was introduced, bacteria were shown to grow in the medium before eventually dying off.

Hence, coconut fiber does have sufficient nutrients to sustain coliform bacteria for a limited period of time once the bacteria are introduced into the medium.

Burnt Rice Husks

Similar tests were run using burnt rice husks as the filtering medium. In all cases where bacteria were present in the feed water, the bacteria died off slowly, showing that the medium did not support bacteria growths. When sterile water was introduced into the filter, no bacteria were observed. Hence, burnt rice husks do not contain nutrients to support bacteria activity.

IV. RESULTS OF VILLAGE SURVEYS COVERING WATER USE HABITS AND SOCIO-ECONOMIC FACTORS

A complete survey of the water use and sanitation habits of villagers in both Ban Som and Ban Nong Suang was undertaken during the months of September/October 1975. The heads of all households were interviewed using a specially developed questionnaire covering basic information on family composition, education, occupation, income and expenditures, and detailed questions on water use habits, sanitation practices, and participation in the filter project. The results of the surveys are summarized and presented in the Appendix B.

Both villages delineated water use and sanitation practices typical of Northeast Thailand. The filtered water from the pilot units was used for drinking and cooking by 76 percent and 78 percent of the families in Ban Som and Ban Nong Suang in the dry season and 33 percent and 13 percent by these villages respectively during the rainy season. Likewise use of the filtered water for bathing and cleaning dropped from approximately 80 to 50 percent during the wet season. Villagers in Ban Som indicated a total water use of about 39 liters per capita per day, and in Ban Nong Suang water use was only 26 liters per capita per day. Water supply was by bucket carrying the filtered water or water from other sources to the household prior to water use. Bathing was twice as frequent in Ban Som as in Ban Nong Suang and gardening was also more common. Both uses are associated with the availability of more water. Both villages complained that the quantity of filtered water made available to them was insufficient and that they were willing and able to pay for the filtered water through monthly water charges. However, the villagers wanted the water fee to be based on actual water use (by metering) or to have the fee vary with the household's income. Currently the water fee is a uniform rate per family regardless of actual use.

The cash incomes of both villages differed significantly. Families in Ban Som averaged in 1974-75 ฿1,585 per family per year (average of 5.6 persons per family) whereas in Ban Nong Suang cash income averaged ฿8,522 per family per year (average of 6.8 persons per family), except for 6 families whose incomes were above ฿50,000 per family. Given that water fees varied from only ฿5-20 per family per month, it is believed that both villages can afford to maintain the water filter projects without the need for outside government assistance.

V. RELATIONSHIP OF TWO-STAGE WATER FILTER WITH LEVEL OF ECONOMIC DEVELOPMENT

A potable water supply in every village has been and still is a development objective of many developing countries. Targets set by individual countries and encouraged by many international agencies have not been met. Even the current efforts worldwide to increase the number of water supplies in rural areas have not kept pace with population growth in the developing countries. Clearly this situation calls for critical examination of our present efforts.

For the provision of water supply in rural communities, the engineer has usually designed the system without any closely defined goal in mind except to provide a potable water supply meeting WHO coliform standards and based on some assumptions of water use, population growth, and peak hourly demand. The question of goals and purposes has been sometimes avoided simply because provision of first-class water services has come to be regarded as essential. However, for the great majority of the world's population who live in rural communities or low-income urban slums, with grossly inadequate access to potable water, there is no possibility that available financial and human resources will provide them with this high level of water provision to which the people of North America and Europe have become accustomed.

A review of government programs to establish village water supply systems in the developing countries, for instance, indicates that a major deterrent to progress is the lack of a defined series of steps towards the ultimate goal of a potable and realiable water supply and the benefits of health and economic growth associated with community water supply. Present approaches are aimed at the ultimate goal in one step. The technologies used are too sophisticated, too expensive to built and difficult to maintain. As an example in Thailand (Ref. 3) conventional rapid sand filter plants built by the Ministry of Health failed to operate effectively because (1) coagulants were expensive and not easily obtained at the village level; (2) lack of understanding how to use coagulants; and the inability of the operators to add the proper dosages; (3) once the coagulation/sedimentation portion of the plant malfunctioned the turbidity load was transfered to the sand filters causing them to clog rapidly; (4) frequent backwashing was not

understood by the operators and often holes were punched into the filter to allow the water to pass through, or the filters were bypassed, both of which resulted in poor effluent quality; (5) breakdown in services caused by improper operation and pump failures resulted in villagers dropping out of the project; (6) inability of the operator to collect sufficient funds to maintain his monthly salary resulted in his cutting back on chemical fuel costs and operating the plant less hours per day; and (7) overall participation was only 60 percent of the village population because the monthly water fees required were above their ability or willingness to pay. These experiences in some 165 village systems clearly indicate that the technology must be brought down to the level where the villager understands it and can use it. The entire set of goals in rural water supply must be reoriented to permit step-by-step achievements towards the desired ultimate water service level. Stage development to achieve the ultimate benefits of health and economic growth appears to be the only feasible approach for rural villages in the developing world.

Where new or modified technologies are being introduced and a lack of experience exists in judging acceptability to the villagers and appropriateness of the project, the stage development approach can be started with several pilot projects. These projects should be small enough to be easily handled, but large enough to be representative. This will permit anticipation of the problems that will occur and help to minimize the risks involved in large-scale undertakings.

Based on the experience gained in pilot testing of the two-stage filter units in rural Thailand, it is believed that the coconut fiber/burnt rice husks filter represents an alternative water treatment scheme which significantly improves the quality of the raw water and which is appropriate to the villagers' level of socio-economic development at this point of time. The two-stage filter unit fits well into the concept of step-by-step development towards an ultimate goals of potable water supply. As such a first step the unit has the following advantageous features:

(a) it is simple to operate so that semi-skilled labor from the village could be responsible for the system;

(b) it makes use of local materials which are readily available, inexpensive and easily understood by the villagers;

(c) it does not depend on imported or foreign made chemicals to function, because such chemicals are little understood and are suspect by the villagers;

(d) the costs of operation and of construction (when amortized over five years for example) are within the means and willingness of the villagers to pay; and

(e) the final effluent is "rain water equivalent" in color, taste, and odor in the eyes of the villagers (i.e., the system does not produce a water of taste or odor objectionable to the villagers as is often the case with disinfected water).

Is such a technology appropriate for water supply development in the rural areas? Chlorination of the effluent can be introduced as a secondary treatment process, distribution of the water to individual homes as a third step, etc.

One study urgently needed is to analyze typical villages of various size groups in Southeast Asia and determine the number of definitive stages that can be delineated by which progressive improvements in village water supply can be made. Starting from a situation of next-to-nothing in facilities to the future goal of international standards, a step-by-step scheme should be carefully defined both for water-in (water supply) and water-out (sewerage), utilizing appropriate technologies and taking into account all of the foreseen socio-economic prerequisites and effects of each step. The study required is analagous to documenting the technical, socio-economic inputs and outputs associated with changes in transportation modes from walking to oxen-drawn carts, bicycles, motorcycles, and lastly motor vehicles. Time, work, social, economic and technical relationships all change as the pattern of transportation forms is changed. Likewise, as water services are introduced to improve quantity, quality, availability and reliability of water supply and sewerage, a wide spectrum of patterns of production, consumption and social activities will change. If these changes can be anticipated and taken into account in the technologies introduced to bring about improvements in village water supply, a significant step forward will be accomplished towards achieving a realistic set of goals for development. What steps might be feasible to make this achievement?

What time period is required for these changes to successfully occur? These are the questions that must be defined by such a study.

VI. SUMMARY AND CONCLUSIONS

A. Summary of Findings

The findings of the Phase II pilot plant study may be summarized as follows:

1. Successful field operation of several filters was accomplished over an extended period of nine months with minimum supervision of the village operators. The filters were operated daily with shut-down times being associated with pump failures and/or repairs only. Changing of filter media was carried out within the same day and no additional shut-down time was experienced. Filter media were changed only two times in the nine month period.

2. Field data indicated that the filters are capable of treating most surface waters successfully without the need for chemicals, except for those waters with abnormally high colloidal turbidities. However, such waters can be treated by the coconut fiber/burnt rice husk filter by adding coagulant chemicals to the raw water and using the first-stage with coconut fiber as an "improved contact" filter.

3. The bacteria removals achieved by the two-stage filters averaged 76 to 86 percent over the nine month period of observation. Bacteria removals varied considerably, however, and individual grab samples ranged from 30 to 100 percent removal. Effluent quality was particularly erratic during the first ten days after media changes prior to the build-up of a biological layer (or "schmutzdecke") on the surface of the media. In all cases disinfection of the final effluent would be necessary to meet recommended international bacteriological standards.

4. The bacteriological removal efficiency of the two-stage filter as compared to slow sand filtration is less efficient (slow sand filters generally show 98-99 percent bacteria removal). However, two important differences need to be noted; (1) the filtration rate of the coconut fiber/burnt rice husk filter is about ten times faster than that of the slow sand filter to reduce size and significantly

save on capital costs; and (2) the slow sand filter could not treat or effectively handle the high turbidity waters found in Southeast Asia without preliminary treatment by either chemical coagulation and sedimentation or roughing filters.

5. The physical quality of the treated waters was generally sparking clear, with of a turbidity of less than 5 JTU, colorless, odorless and without any noticeable taste. Turbidity removals were generally greater than 80 percent and as high as 97 percent. In general, treated water met WHO International Standards for clarity, taste, odor, and color.

6. The ability of the coconut fiber/burnt rice husks filter to effectively treat highly turbid waters can be extended by "improved contact filtration" wherein a coagulant, such as aluminum sulfate, is added to the incoming water to increase the partical size of the colloidal materials and thereby enable better contact with the coconut fibers in the primary filter stage. Because the fiber does not have a small effective pore size (as sand for example), the length of filter run continues until the fiber becomes clogged with mud. The turbidity load is then carried over to the second stage filter. A raw water of turbidity level 300 to 600 JTU, containing as much as 50 percent of its turbidity as colloidal material of 7 microns size or less, was successfully treated in this manner. Overall turbidity removals ranged from 85 to 97 percent and averaged 93 percent over the entire filter runs. Fecal coliform removals were reduced from the raw water content of 500 to 3,000 MPN per 100 ml to the range 3 to 45 MPN per 100 ml. Bacterial removals averaged 96 percent.

7. By increasing the number of stages from two to three, the length of the filter runs using the "improved contact filtration" method increased over 100 percent from 31 hours to 75 hours per filter run. The unit was stopped when the effluent showed a deterioration in water quality which was indicated by an increase in turbidity above 20 JTU.

8. The "improved contact filtration" scheme produced more filtered water (of comparable quality) than the sedimentation dual filter

scheme per square meter of surface area per hour of operation. Output could be increased from less than 20 m^3/day to 60 m^3/day for the large pilot unit at Ban Nong Suang. However for longer filter runs and more reliable output, a three-stage improved contact filtration scheme would be required. The coconut fiber filters could then be alternately cleaned to provide continuous output.

9. An individual family size single container dual media filter was developed and tested using a filtration rate of 0.8 $m^3/m^2/hr$. The effluent from the filter was satisfactory only in terms of producing a low turbidity water. Bacteria removals were low and varied radically.

10. Use of a single container individual family size filter requires the addition of a simple chlorinator to insure significant bacteriological removals. The single container while simple and inexpensive, lacks the additional treatment efficiency of a two container unit. Using a simple coconut shell chlorinator submersed in the raw water above the filter, chlorination at chlorine dosages of about 1.0 mg/l produced near zero coliform levels in the effluent. Results were sporatic however due to the short detention time in the unit.

11. Villagers were enthusiastically satisfied with the quality of the treated water and utilized the filtered water for drinking, cooking and (when available in sufficient quantity) for house cleaning, and personal hygiene.

12. Operational problems were minimal. The filters were operated two to five months between changes of filter media. Changes were made by washing the coconut fiber in the raw water to remove the entrapped mud, then replacing the washed fibers back in the filter for reuse, and by scrapping off the upper 10-15 cm of burnt rice husks and discarding them before beginning a new filter run. Shut-down time was less than one day for changing the filter media.

13. Considerable interest was generated in neighboring villages and in several Ministries responsible for providing water supply, in the potentials for building and operating other filter units using coconut fiber and burnt rice husks.

B. Comments on Questions Raised in Document, "E.O. 11652:N/A, EARP: SEATEC/FRANKEL Proposal for RED on Coconut Husk/Burnt Rice Husk Filter, 7/6/74"

Most of the information requested in the subject document is provided in the body of the report. Additional information relating to specific points is as follows:

1. Confidence Levels

95% confidence level statistics were calculated for bacteriological data evaluating the performance of the filters to remove both coliform and fecal coliform bacteria. Due to the large value of the standard deviations of bacteria levels in both the raw and filtered waters, the 95% confidence interval of the variable ranged from 0 to 100 percent. Subsequently a 95% confidence interval of the mean was calculated which indicates that the mean value will fall within a specified range with 95% confidence. Bacteriological removals are shown in Tables 1 through 4 with these statistics. Using all samples points, coliform removals from Ban Nong Suang and Ban Som will average 71 to 83 percent and 54 to 70 percent respectively with 95% confidence. Using data points after the first ten days of operation to allow for build-up of the biological layer, coliform removals from Ban Nong Suang and Ban Som filters will average 82 to 89 percent and 71 to 86 percent respectively with 95% confidence.

2. Time Period to Reach Steady State Conditions

A ten day start-up period was found to be typical before a well developed biological layer formed on the filter media. The rate of filtration was not changed to account for this ripening period. Bacteria removals were more consistent after this ten day start-up period. Turbidity removals were generally consistent after only one day of operation.

3. Minimum Filter Operating Conditions to Obtain Desired Water Quality

As previously explained, the filter effluents do not meet recommended international standards for bacteria levels without the addition of disinfection. The effluents generally meet recommended standards for

clarify, taste, odor and color following start-up conditions (after media changes) and throughout the filter run. Therefore, it is believed that the operator should use the general criterion that when the rate of flow decreases to approximately one-half (50 percent) of the initial flow rate (when the media are new) that it is time to change the filter media. A simple turbidity criterion is also believed to be useful for guidance of the operator; e.g. when the turbidity exceeds 10 or 20 JTU, the media should be changed. It is not worthwhile to recommend filter media changes as a function of coliform tests.

C. Significance of Bacterial Removals

One of the key parameters commonly used in evaluating water filtration performance is the efficiency in removing coliform organisms, and the residual coliform densities in the treated effluent, as related to the usual standards required for drinking water (essentially 1 coliform per 100 ml, in the USA).

A review of the subject indicates, for the highly turbid surface waters of the type dealt with in this study, that the following estimates may be made of the probable performance of various types of filters or treatment systems without the addition of disinfection, assuming an average initial turbidity of 50 JTU and an average initial coliform concentration of 2,000/100 ml:

Type of Filter	Average Removal Efficiency, %	Residual Coliforms/100 ml
(1) Slow sand filter		
(a) Without pretreatment	Rapid clogging of media	-
(b) With pretreatment	98 - 99.5	10 - 40 (Ref. 4)
(2) Rapid sand filter	98	40 (Ref. 4)
(3) Two-stage (CF/BRH) filter		
(a) Without chemicals	76 - 86	280 - 480
(b) With chemicals in first-stage	96	80

All filters, regardless of pretreatment, cannot be expected to meet the usual standards required for drinking water without the addition of disinfection, particularly when coliform levels are as high as those experienced with the pilot projects.

Quantification of the health benefits in rural areas associated with improved bacteriological water quality is not available with a reduction in coliform levels from 2,000 to 200, 50 or even 1 per 100 ml.

In the medical literature disease levels have been decreased significantly and even erraticated with an innoculation of 60-70 percent of a diseased population. Whether or not 60-70 percent reduction in overall coliform or fecal coliform removal will significantly reduce the incidence of water borne diseases in a population is not known. Clearly filtration alone is not sufficient to guarantee that the water is safe for drinking given the assumption that potability means ≤ 1 coliform/100 ml. Disinfection would be required before bacteria levels could be reduced to recommended international standards.

From the village surveys conducted in the project villages, sanitation habits indicate that transmission of waterborne diseases is equally likely by hand to mouth contact. Thus the water quality criteria alone are not sufficient to guarantee improved health. The water project must be viewed from the broader prospective of being a first step towards health improvement, active community participation and support in community development, benefits in terms of time and energy savings, and water supply improvements in terms of availability and reliability.

D. Conclusions

The coconut fiber/burnt rice husk filters can be operated easily and inexpensively by unskilled operators in rural communities. The units operate relatively effectively with minimum maintenance requirements. Filter media can be prepared in advance or obtained locally in abundant quantities and at low costs. The filters will produce from most surface waters, without the aid of chemicals, an effluent meeting recommended standards of clarity, taste, odor and color. Bacteriological efficiency

is less than slow sand filter systems and averages 76-86 percent. To meet internationally recommended coliform standards, disinfection will have to be introduced as an additional process

Effluent quality is readily accepted by the villagers. Operation costs can be paid for by minimal monthly water fees collected from the users without the need for central government support. The coconut fiber/burnt rice husks filter appears to be a logical development step in a series of steps to achieve a high level provision of water services in the rural environment.

VII. FUTURE RESEARCH NEEDS

The Phase II pilot study has accomplished the objectives outlines in proposal. Several new ideas and unanswered questions present themselves as attractive research areas for future work as a result of the successful operation of the pilot plants as shown in Figure 1 covering the sequential development of the filter research program. These ideas include the "improved contact filtration" technique to extend the range of waters that can be treated by the two-stage filter, the use of a simple coconut shell type chlorinator to achieve lower residual bacteria levels in the filtered effluent, and the further simplification of filter unit construction to lower capital as well as operating costs. These research areas include the following:

1. Continuation of the pilot plant study at Ban Nong Suang, Korat Province to improve the design and operation of the "improved contact filtration" scheme by using multiple coconut fiber stages and by reducing the coagulant level fed to the raw water;

2. Field test the introduction of a simple chlorinator in the villages of Ban Som and Ban Nong Suang both before and after first-stage filtration in order to improve chlorinator design, test efficiency of operation, and to record villages reactions;

3. Carry out a detailed physical-chemical analysis of the properties of coconut fiber and burnt rice husks as to why these materials work effectively on most waters in removing turbidity, color, taste and odor, including a definition of quality characteristics or properties needed to insure effectiveness of the fiber media;

4. Continue field testing of the improved design of the individual family-size jar filters;

5. Introduce and record villager reactions to the introduction of hand and/or bicycle operated pumps in Ban Som and/or neighboring villages that expressed interest in the coconut fiber/burnt rice husks filters;

6. Carry out a systematic program of research and development to define a series of steps for both water-in (watersupply) and water-out (sewerage), utilizing appropriate technologies and taking into account all of the foreseen socio-economic prerequisites and effects of each step. As a product the study report could propose a program for 20 villages over a ten year period to document the effectiveness of the step-by-step approach.

VIII. ACKNOWLEDGEMENTS

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APPENDIX A

LIST OF REFERNECES

1/ 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 Institute of Technology, Bangkok. Also Development and Field Testing of the Coconut Fiber/Burnt Rice Husk Filter, Interim Report, Southeast Asia Technology Co. Ltd., Bangkok, May 1975.

2/ Talib bin Latiff, Abdual, et al (1972), The Pahang Continuous Chlorinator (Coconut Type), Public Health Services Section, Ministry of Health, Pahang, Malaysia.

3/ Frankel, R. J. (1975), Evaluation of Community Water Supply Systems in Thailand, Water Resources Research, Vol. 11, No. 3, June.

4/ Salvato, J. A. (1958) Environmental Sanitation, John Wiley & Sons, Inc., New York.

APPENDIX B

INDIVIDUAL HOUSEHOLD QUESTIONNAIRES
SUMMARY OF RESULTS FOR BAN SOM AND BAN NONG SUANG
KORAT PROVINCE, SEPTEMBER 1975

Information on Interviewee & Household

		Ban Som	an Nong Suang
1.	Interviewee		
	Total	104	110
	Head of household	63	93
	Housewife	37	17
	Other	4	-
2.	Sex of head of household		
	Male	61	94
	Female	35	16
3.	Age of Interviewee		
	16 - 30	9	21
	31 - 40	17	21
	41 - 50	23	29
	51 - 60	27	23
	>60	24	16
4.	No. of children		
	0 - 1	8	10
	2 - 3	21	21
	4 - 5	25	33
	6 - 7	27	26
	>7	21	20
5.	Number of persons in household		
	1 - 4	37	17
	5 - 6	32	36
	7 - 8	16	32
	9 - 10	9	11
	11 - 12	7	11
	>12	1	3

	Ban Som	Ban Nong Suang
6. Age of numbers of household		
0 - 1	15	45
1 - 5	34	95
6 - 10	55	100
11 - 15	68	73
16 - 20	77	94
21 - 25	89	90
26 - 30	54	63
31 - 35	38	28
36 - 40	26	25
41 - 50	46	60
51 - 60	51	49
61 - 70	27	21
> 70	7	3
Total	587	746
(15 years & under	172	315
%	29.3	41.9
20 years & under	249	409
%	42.4	54.8)
7. Level of education of head of household		
Illiterate	14	2
Below grade 4	14	11
Grade 4	65	96
M.S. 3	1	1
M.S. 5	-	1
8. No. of illiterate persons older than 15 years of age	18	4

(2) Sanitary Information

	Ban Som	Ban Nong Suang
1. Numbers of your household getting sick during the past year (1975).		
Headache, fever	534	702
Sore throat, cough, cold	500	719
Intestinal disease	29	35
Worm diseases	25	10
Kidney disease, calculus	2	1
Mental disease	8	2
Gye disease	44	8
Skin disease	42	24
Cholera, diarrhoea	40	10
Typhoid	-	-
Nutrition disease	1	1
Others eg. Haemorrhage	3	5
2. What do you do when any member of your household gets sick.		
Nothing	-	-
Buy medicine yourself	94	104
See a spirit doctor	7	-
See a quack	2	-
See a Tambon doctor	1	6
See a Thai old style doctor	2	-
See a nurse or a midwife	1	-
Go to health center	11	79
Go to hospital or clinic	70	62
3. When you eat local foods made of pork & meat, do you cook it?		
Eat uncooked foods	13	-
Eat half-cooked foods	16	6
Eat well-cooked foods	77	24

	Ban Som	Ban Nong Suang
4. When you eat vegetables, do you usually clean them before eating?		
Never clean	-	-
Clean sometimes	7	4
Clean frequently	46	4
Everytime	82	102
5. How do you eat your meals?		
With hand	91	104
With spoon & fork	8	12
With spoon	48	5
With chopstick	-	-
6. Do you wash your hands before having meals?		
Never	-	-
Sometimes	-	-
Everytime	110	98
7. What kind of privy do you have?		
None	8	31
A privy inside the house	-	3
A privy outside the house	92	65
A septic tank without cover	-	3
A septic tank with cover	-	9
8. How often do you use your privy?		
Everytime	75	63
Sometimes	19	16
Never	7	27
9. Do you wash your hands after going to privy?		
Never	11	-
Sometimes	15	1
Everytime	68	109

	Ban Som	Ban Nong Suang
Do you wash your hands with soap?		
Yes	24	13
No	75	97

10. What kind of water do you use for drinking?

Kind of Water	Dry Season		Rainy Season	
	Ban Som	Ban Nong Suang	Ban Som	Ban Nong Suang
Filtered water	79	86	34	13
Rain water	48	59	95	109
Well water	38	8	4	2
Water from pond or reservoir	32	-	5	-
River water	12	-	-	-

11. What do you do with the water before drinking?

Description	Dry Season		Rainy Season	
	Ban Som	Ban Nong Suang	Ban Som	Ban Nong Suang
Nothing	85	109	90	109
Coagulate with alum	-	-	-	-
Boil, sometimes	12	1	4	2
Boil everytime	3	-	-	-

12. What kind of water do you use for bathing & cleaning?

Kind of Water	Dry Season		Rainy Season	
	Ban Som	Ban Nong Suang	Ban Som	Ban Nong Suang
Filtered water	34	94	28	51
Rain water	29	14	79	72
Well water	54	48	30	36
Water from pond, or reservoir	59	12	37	7
River water	65	-	40	-

13. How many buckets of water do you use each day?
(1 bucket ~15 liters)

Description	Ban Som	Ban Nong Suang
For Drinking	154	160
For cooking	337	287
For washing, bathing	673	782
For gardening	337	60
For others	9	-
Total	1,510	1,450
No. of families	104	110
Total population	587	746
Persons/family	5.6	6.8

Quantity of Water Used

Description	1/day/capita	
	Ban Som	Ban Nong Suang
By Family		
Drinking	4	3
Cooking	9	6
Washing, bathing	17	16
Gardening	9	1
Others	-	-
Total	39	26

Description	1/day/family	
	Ban Som	Ban Nong Suang
Drinking	22	22
Cooking	49	39
Washing, bathing	97	107
Gardening	49	8
Total	217	176

Average number of buckets carried per family per day

Ban Som = 14.5

Ban Nong Suang = 13.2

Average water use (bucket/person/day)

Description	Ban Som	Ban Nong Suang
Drinking water	0.26	0.21
Cooking water	0.57	0.38
Washing, bathing water	1.15	1.05
**Water for gardening	0.57	*
Total	2.57	1.94

* Only 1 information available (see table below).

** Used in great quantities by only a few households.

Table Showing Numbers of Family VS.
Quantity of Water Used for Household (in buckets)

Buckets	Drinking Water		Cooking Water		Washing & Bathing Water		Water for Gardening		Others	
	B.S.	B.N.S.	B.S.	B.N.S.	B.S.	B.N.S.	B.S.	B.N.S.	B.S.	B.N.S.
1 - 5	101	100	79	115	32	34	2	-	3	-
6 - 10	-	-	12	3	53	61	5	-	-	-
11 - 15	-	-	-	-	4	13	3	-	-	-
16 - 20	-	-	-	-	2	2	8	-	-	-
>20	-	-	-	-	-	-	-	1	-	-

No. of persons used for calculation Ban Som = 587 persons

Ban Nong Suang = 746 persons

14. How often do you bathe?

Description	Ban Som	Ban Nong Suang
Once every other day	-	2
Once a day	31	99
Twice a day	44	9
More than twice a day	38	1

15. How much water do you store?

Description	Dry Season		Rainy Season	
	Ban Som	Ban Nong Suang	Ban Som	Ban Nong Suang
Big jars	151	53	162	306
Small jars	109	320	115	642

1 big jar = 1,000 liters

1 small jar = 160 liters

Table Showing Quantities of Stored Water at the Two Villages

No. of Jars	Dry Season				Rainy Season			
	Big Jar		Small Jar		Big Jar		Small Jar	
	B.S.	B.N.S.	B.S.	B.N.S.	B.S.	B.N.S.	B.S.	B.N.S.
1 - 5	55	27	50	51	57	29	53	48
6 - 10	6	2	2	33	17	4	10	36
11 - 15	-	-	-	-	1	3	-	7
16 - 20	-	-	-	-	2	1	2	1
>20	-	-	-	-	-	-	-	1

16. Do you use filtered water for vegetable gardening? 100% No.

17. When do you use filtered water?

Description	Ban Som	Ban Nong Suang
During dry season only	73	19
Throughout the year	13	14
Throughout the day	3	2
In the morning & evening	56	75
Never use	12	-

	Ban Som	Ban Nong Suang
18. Do you like the taste of filtered water?		
Yes	93	92
50% - 50%	4	17
No	-	-
19. Do you get enough filtered water for your household consumption		
Yes	27	40
Sometimes	14	69
No.	49	-
20. After having the system, your use of water has		
Increased	62	3
Decreased	17	-
Stayed the same	13	106
21. How much do you pay for the filter water?		
1 - 5 Baht per family per month	91	-
5 - 10	1	105
10 - 15	-	-
15 - 20	1	5

	Ban Som	Ban Nong Suang
22. What do you think of the present rate of water is		
Just	98	107
Unjust, because could not get water when needed	-	3
23. Do you think that the present rate is		
Not expensive	94	105
Expensive	4*	5
* If expensive, the rate should be ฿5 a month (Only those saying the fee is expensive)		
24. In case the filter water is not available		
Who will fetch the water?		
Daughter	73	55
Son	28	25
Other	20	54
The fee of the filtered water should be		
calculated according to meter readings	45	21
The same for every household	1	1
Vary with households' income	46	88
Time spent in fetching water		
0.5 - 1 hr	71	103
1 - 2 hr	22	3
25. What do you think can keep you healthy?		
Don't know	-	1
Eat sufficient food	36	99
Eat clean & cooked food	4	32
Eat useful food	13	25
Drinking clean water	70	109
Clean house	19	10
Clean clothes	56	7
Good & fresh air	6	4
Sufficient exercise & moderate works	6	3
Vaccination and other treatments when recommended by the health officer	93	72

	Ban Som	Ban Nong Suang
26. In case the filtered water is available, do you want to have the pipeline extended to each house?		
Yes	89	76
No idea	3	12
No (Short of money or no public tap water available near the residence)	8	6
27. Do you use tap water?		
No, no tap water nearby	12	1
Yes, filtered water piped to the house	2	-
Yes, filtered water	89	93

(3) Information on Income & Expenditure

1. Income from the following items last year (for the entire household)

Key 1.1 Selling rice
1.2 Selling vegetable, fruit (most from tapioca)
1.3 Selling jute, kenaf, kapok
1.4 From land renting, animal lease
1.5 From home industries
1.6 Profits from trading
1.7 From salary & wages
1.8 Total income

Ban Som

Key	฿1-500	฿500-1,000	฿1,001-2,000	฿2,001-3,000	฿3,000	Note
1.1	1	2	3		1	Several families
1.2	2	4			4	did not give the
1.3	3	12	16	1	3	information on
1.4	1					their incomes/
1.5	2					expenses.
1.6	1	1	1			
1.7	7	1	4	2	1	
1.8	8	13	18	9	11	

Ban Nong Suang

Key	1-500	501-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-10000	10000
1.1								
*1.2	1	3	11	8	12	7	32	24
1.3								1
1.4								
1.5								
1.6	2			3	1	1	2	
1.7	1	1						1
1.8	3	6	8	8	12	9	37	26

*all from selling tapioca

Average Income

1. Ban Som ฿1,585 per family/year

2. Ban Nong Suang

(a) Average for 108 families = ฿14,022 per family/year

(b) There were 6 families earning more than ฿50,000 per year (i.e. ฿50,000; ฿85,000; ฿100,000; ฿110,000; ฿100,000 and ฿200,000). Their total earning were about 42 percent of the village's grand total income. So these six families did not seem to represent the village's 108 families.

If only the other 102 families along are considered, the average income = ฿ 8,522 per year.

(Actual data, not the upper limits, were used in these calculation.)

2. Money left over last year

Baht	Ban Som	Ban Nong Suang
0–	65	78
1 – 500	11	10
501 – 1,000	6	3
1,002 – 2,000	3	7
2,001 – 5,000	2	6
5,001 – 10,000	–	3
10,000	–	1

3. What are the three largest expenditures paid last year?

Items	Ban Som	Ban Nong Suang
3.1 None	-	-
3.2 Food	98	109
3.3 Clothes	98	96
3.4 Education	30	47
3.5 Medicine & treatment	81	85
3.6 Agricultural supply (not including the lands)	10	28
3.7 Home industrial materials	-	-
3.8 Land or other investment	3	2
3.9 Gold, jewelry	2	-
3.10 Wage payment	1	-
3.11 Debt and interest payment	-	1
*3.12 Wages for tapioca growing & harvesting	-	97

*Should be combined with 3.6

FIGURE I

SEQUENTIAL DEVELOPMENT OF THE COCONUT FIBER/BURNT RICE HUSK FILTER RESEARCH PROGRAM

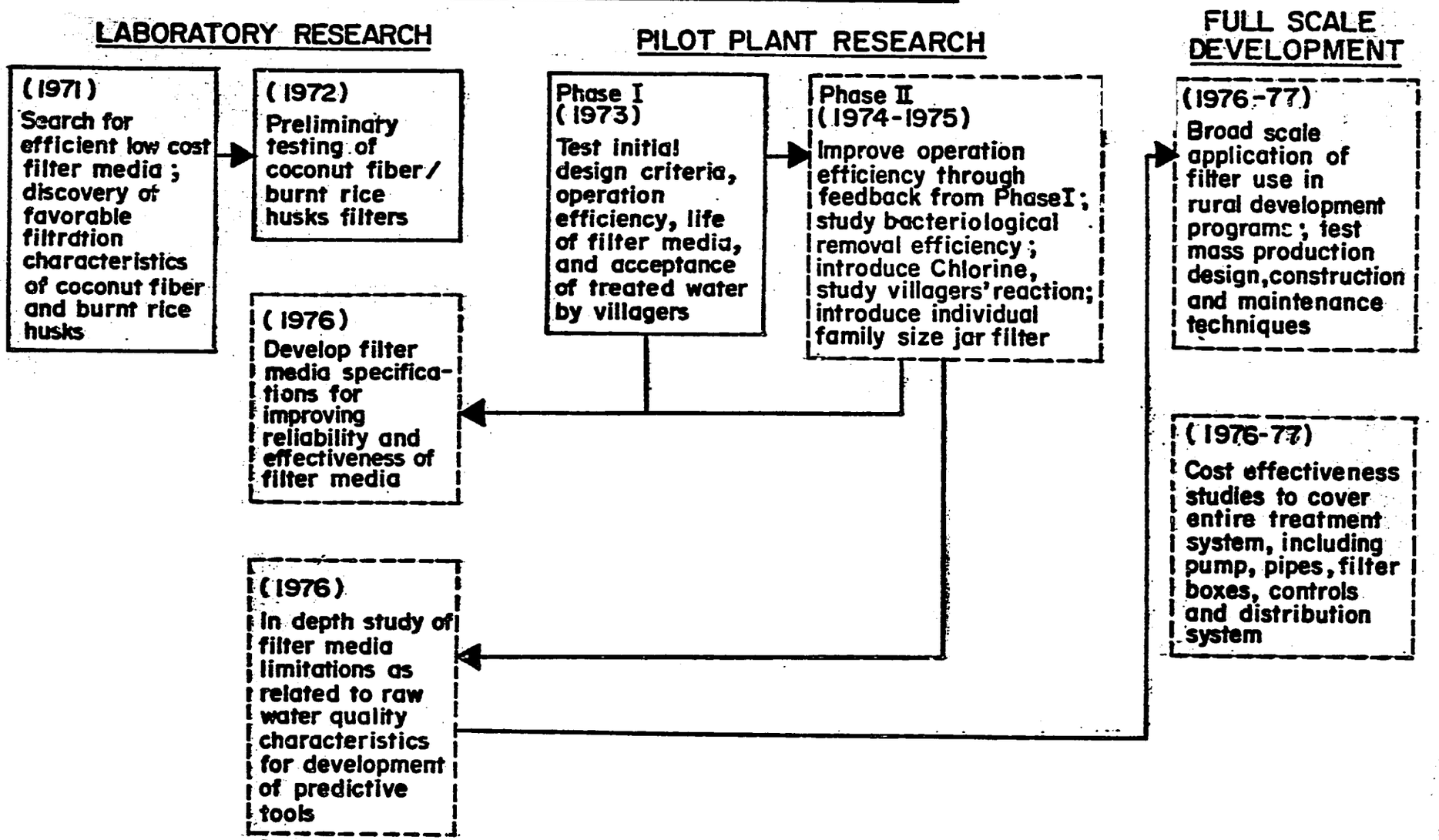
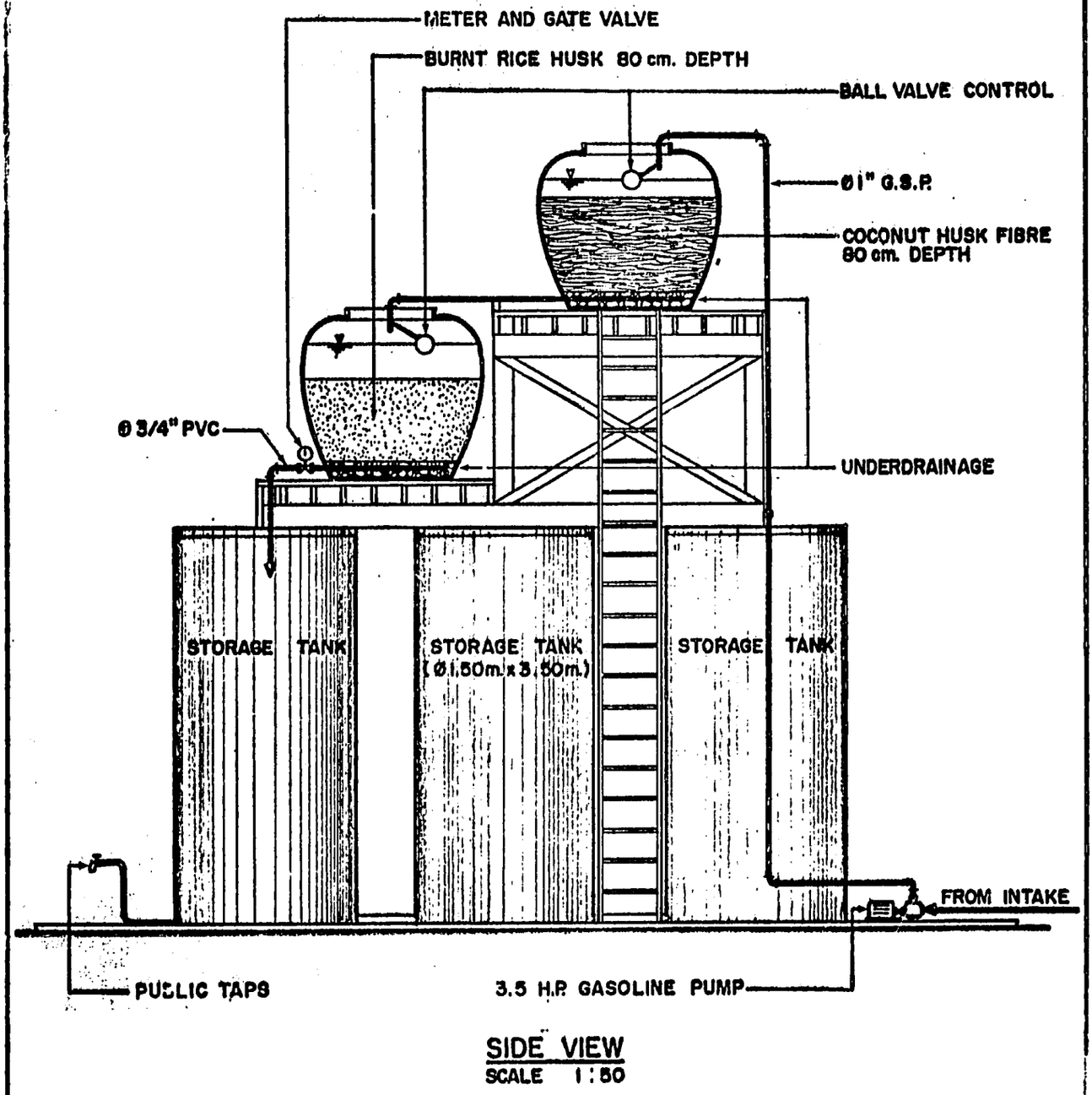


FIGURE I



SIDE VIEW
SCALE 1:50

FIGURE 2

TWO-STAGE FILTRATION UNIT AT BAN SOM, KORAT PROVINCE

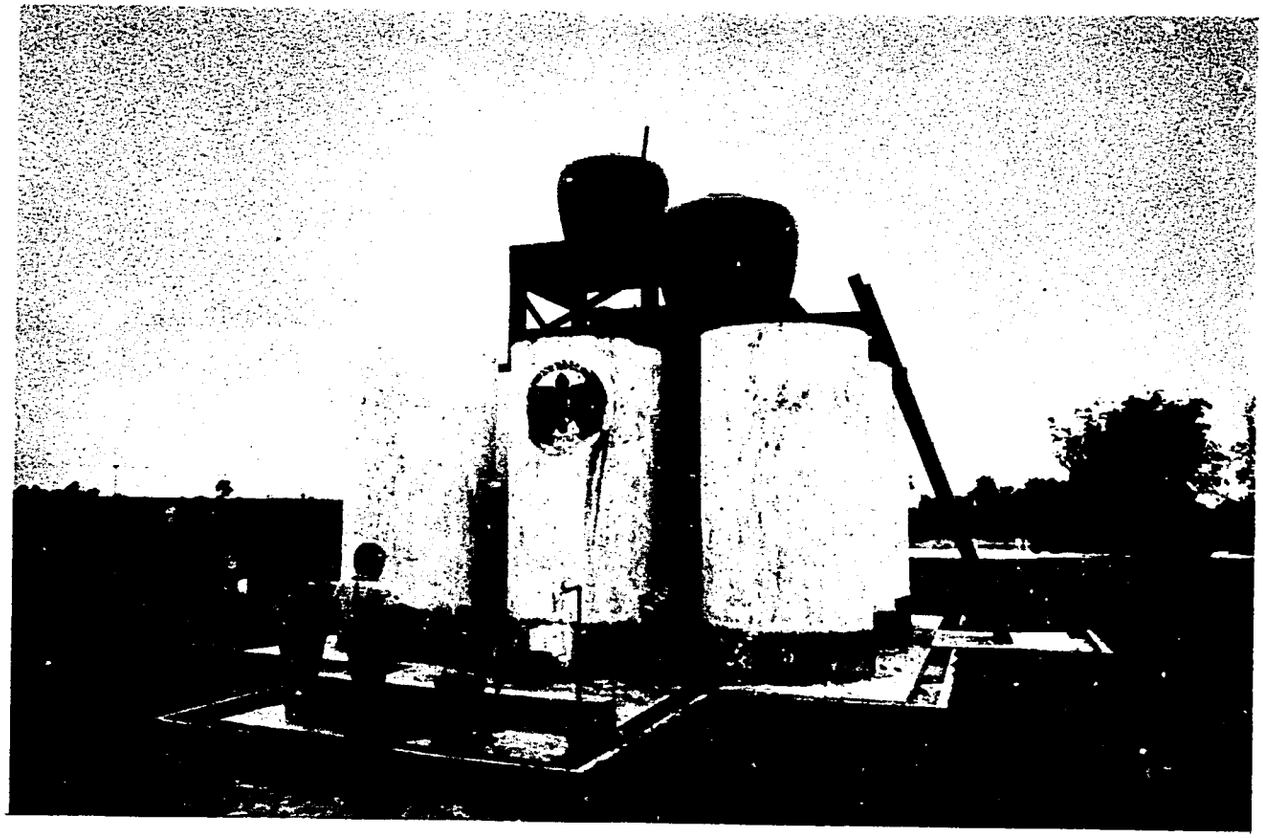


FIGURE 3

PHOTOGRAPH OF COMPLETED 1.25 $m^3/m^2/hr$ TWO-STAGE FILTER UNIT AT BAN SOM, KORAT PROVINCE

FIGURE 3

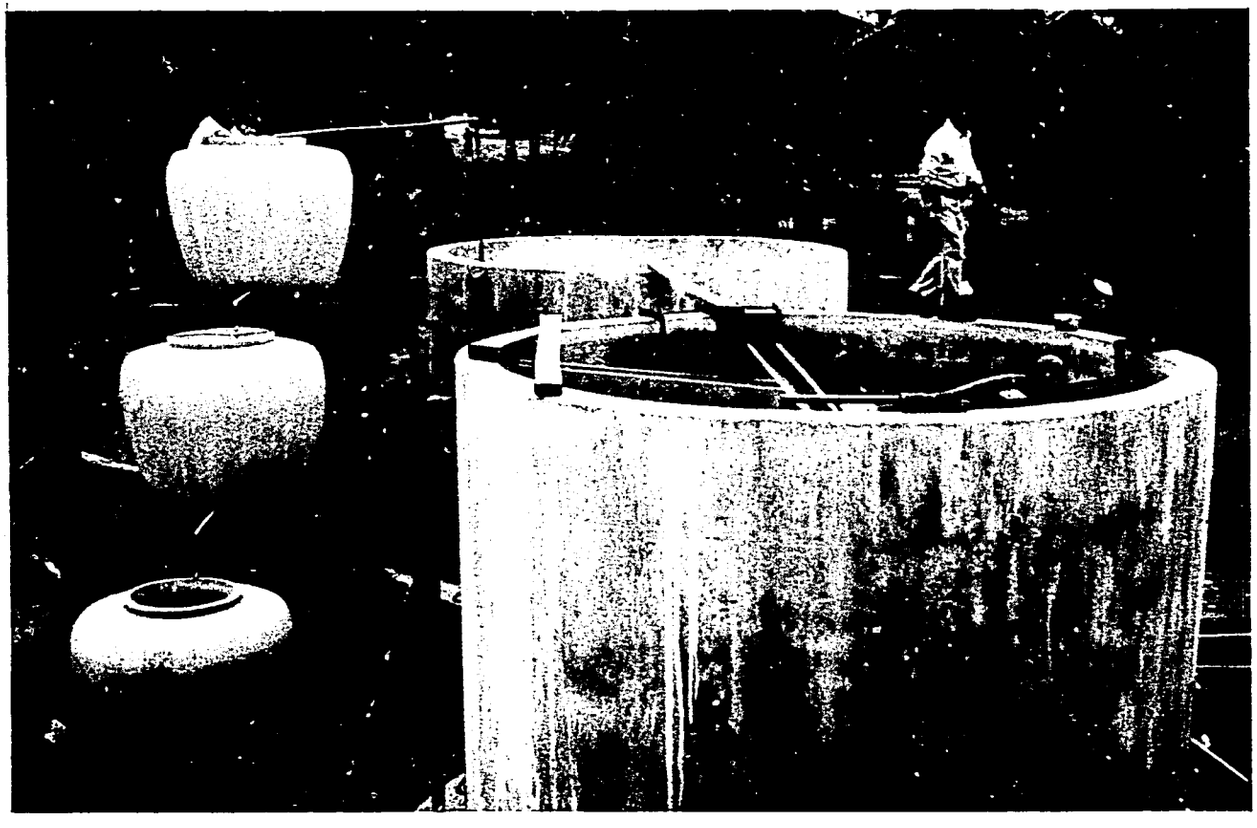


FIGURE 4

PHOTOGRAPH OF PILOT WATER FILTER PROJECTS AT BAN NONG SUANG, KORAT PROVINCE

(1 m^3/hr and 15 m^3/hr Capacity Units Left and Right Sides Respectively)

FIGURE 4

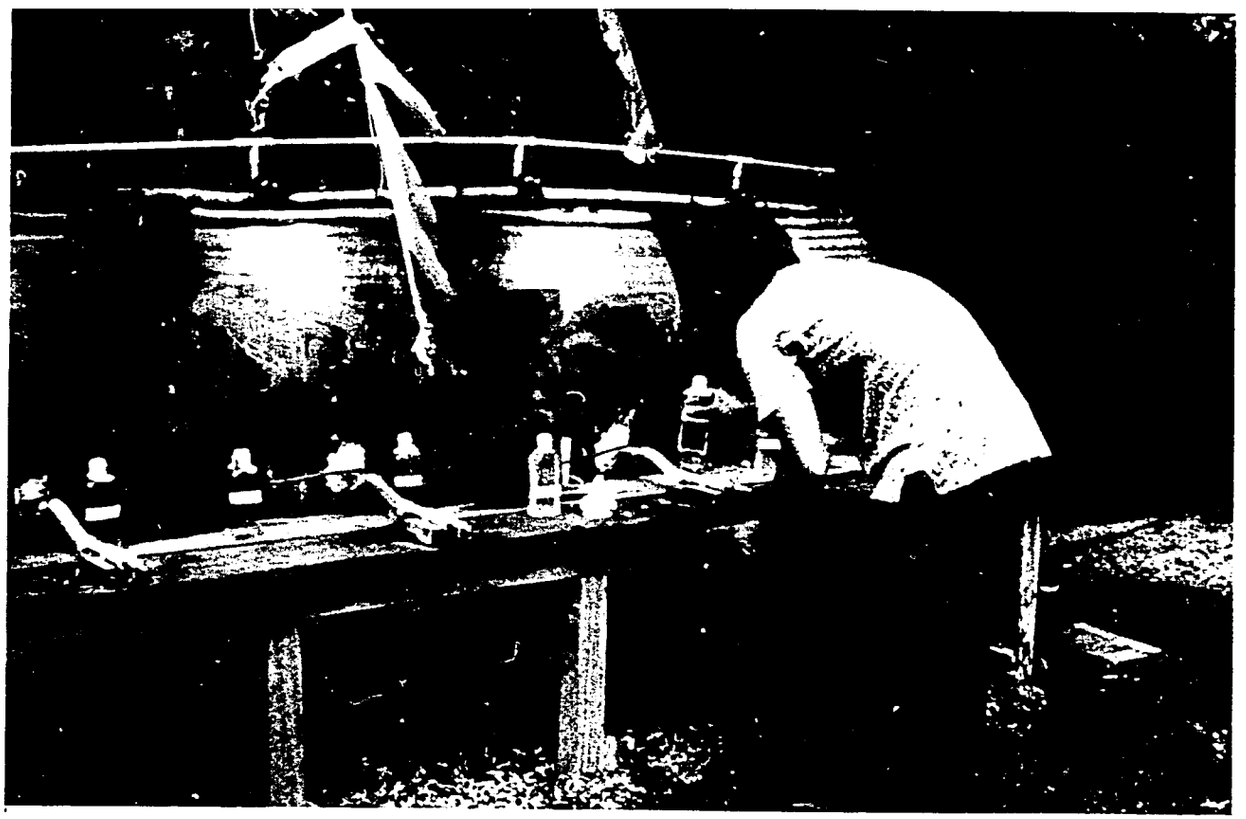


FIGURE 5

PHOTOGRAPH OF INDIVIDUAL FAMILY SIZE JAR FILTERS USING PRESSURE RELEASE VALVES

(Samples Being Taken for Bacteriological Analyses)

FIGURE 5

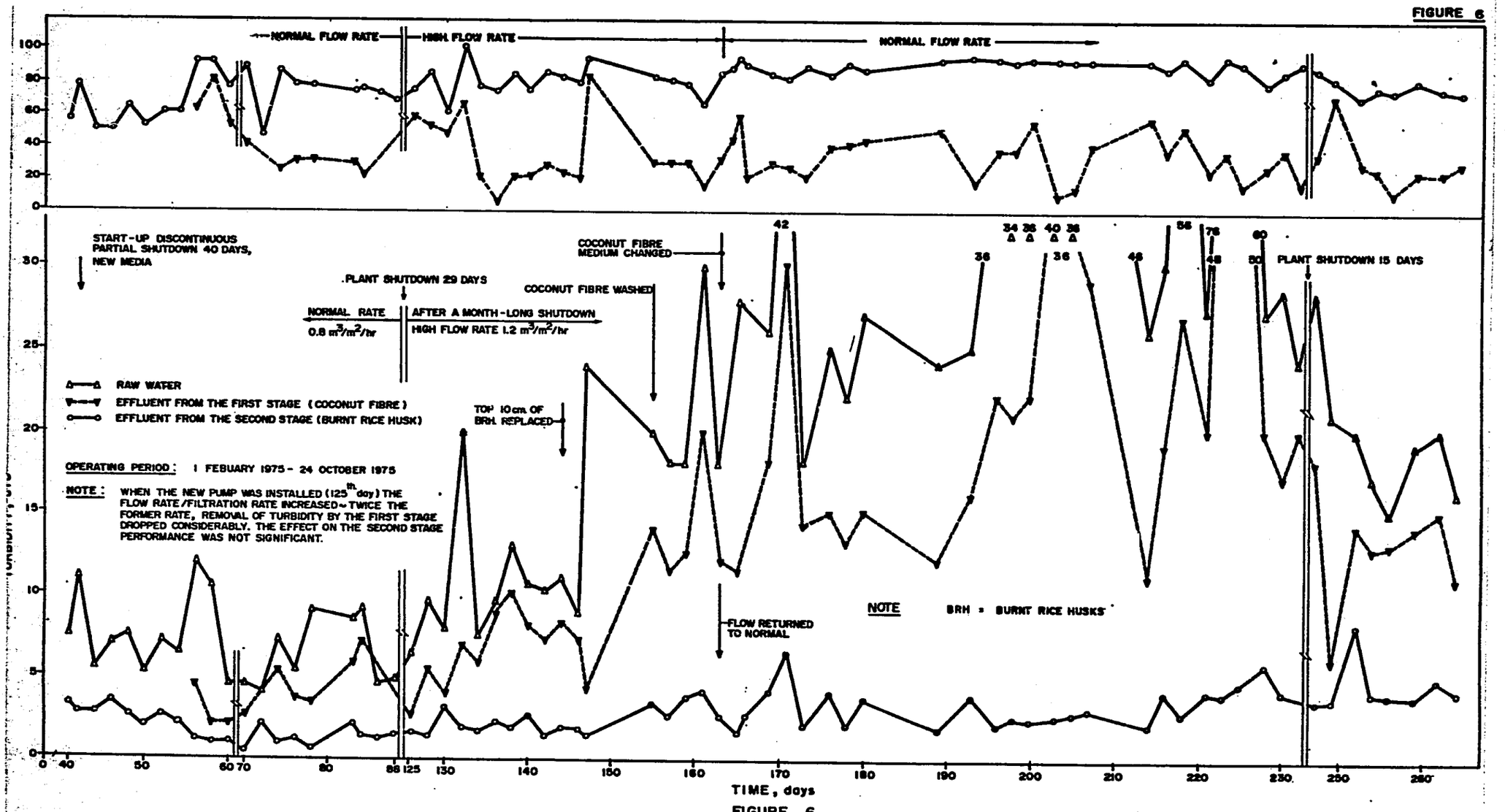


FIGURE 6

TURBIDITY AND REMOVAL OF TURBIDITY FOR BAN SOM UNIT

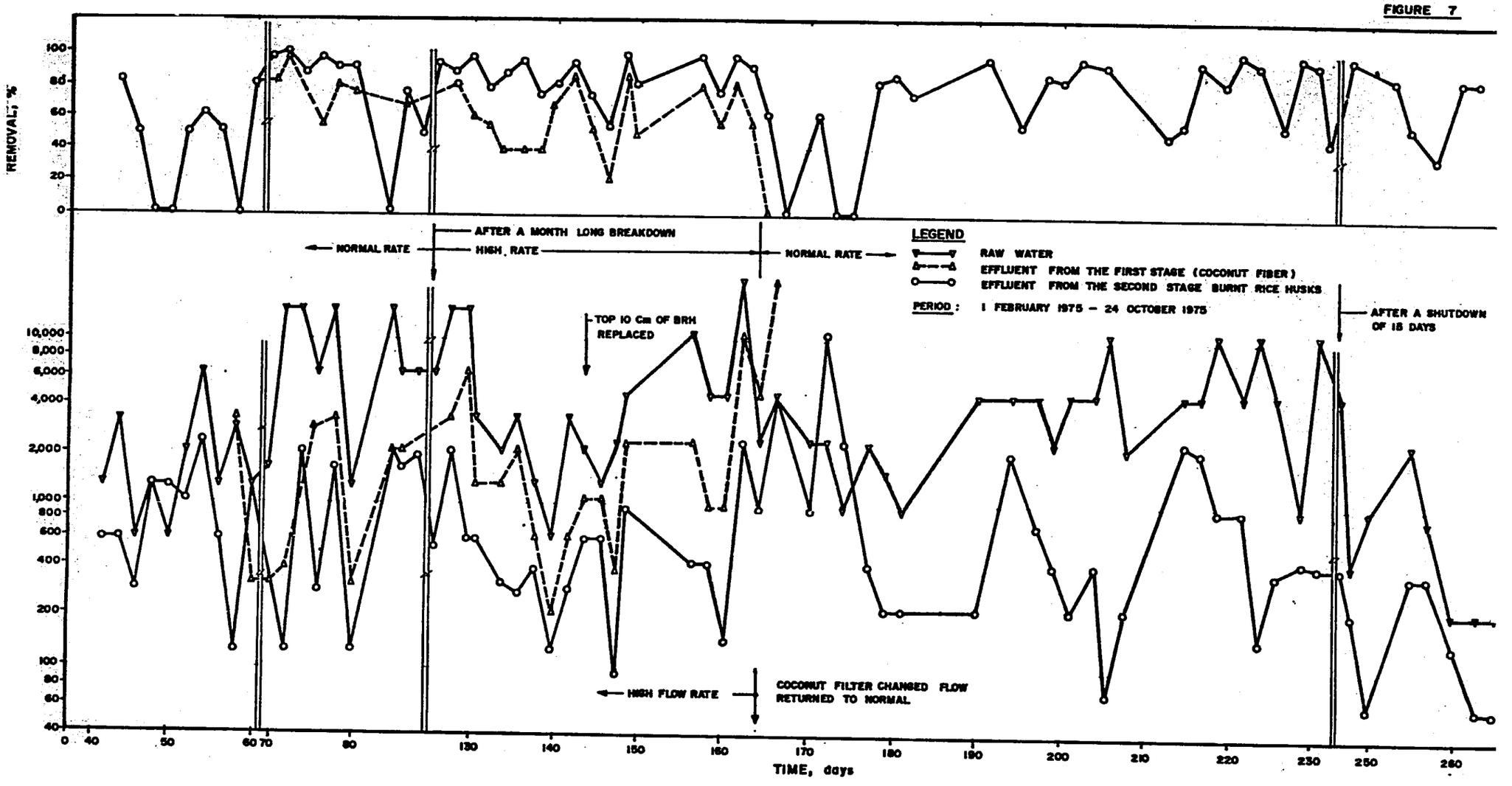


FIGURE 7

REMOVAL OF COLIFORM BACTERIA BY FILTER UNIT AT BAN SOM

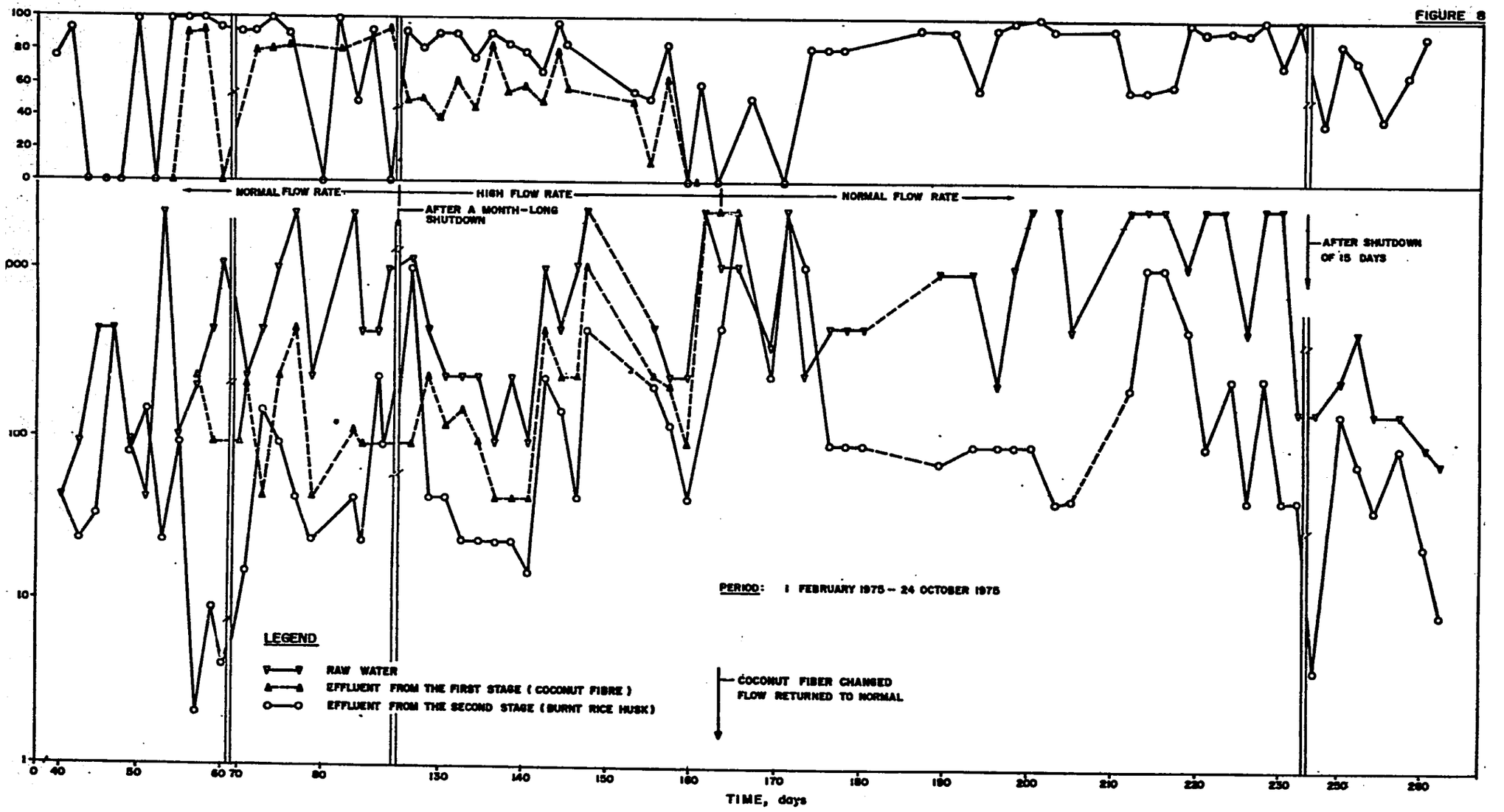


FIGURE 8

REMOVAL OF FECAL COLIFORM BACTERIA BY FILTER UNIT AT BAN SOM

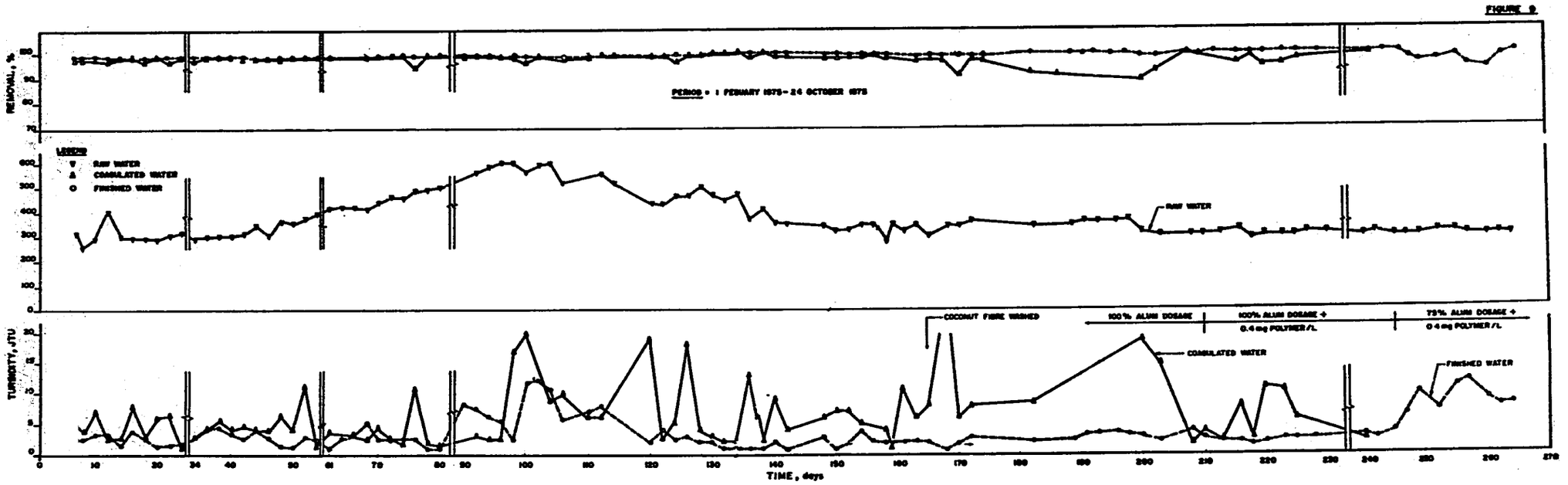


FIGURE 9

REMOVAL OF TURBIDITY BY BAN NONG SUANG LARGE SCALE UNIT

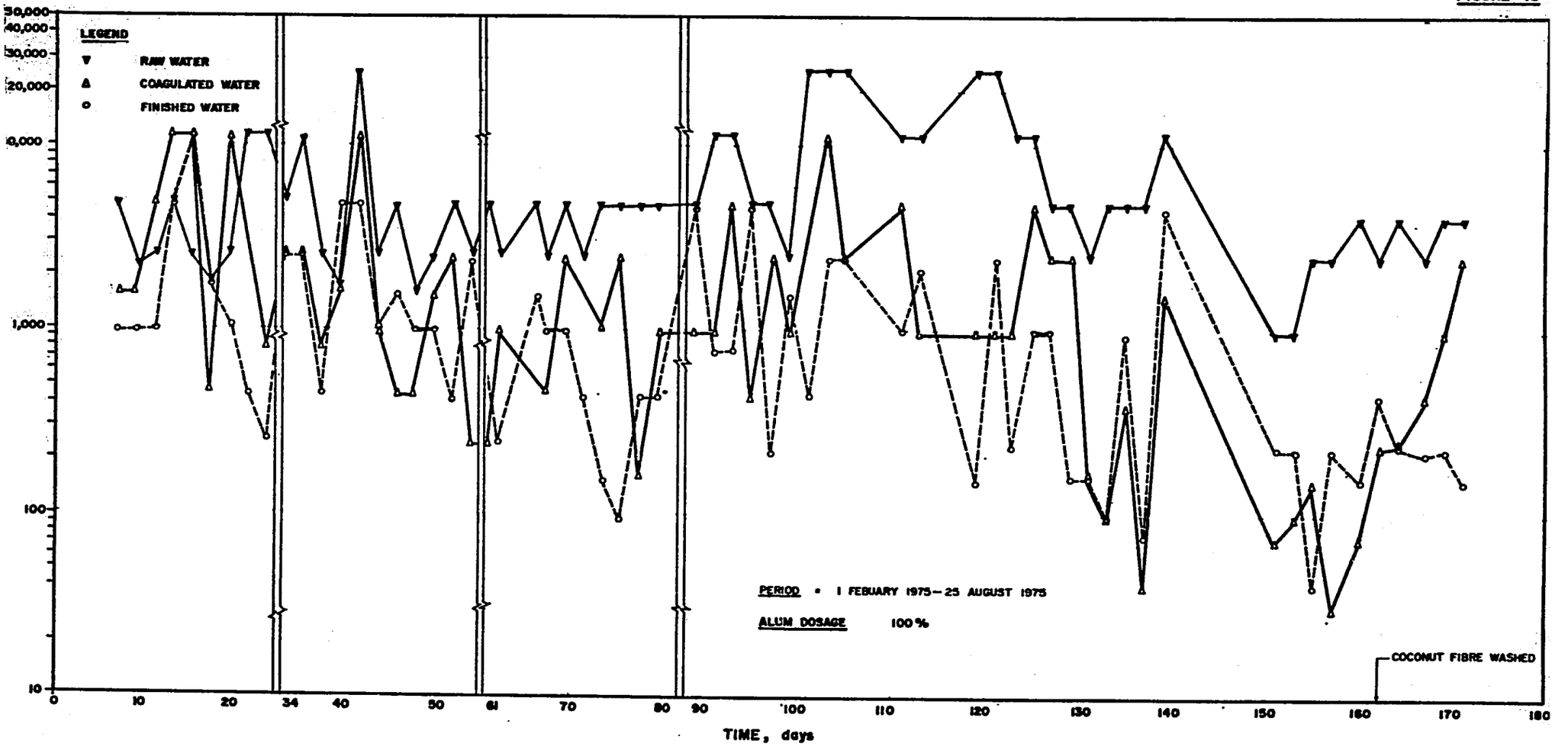


FIGURE 10

REMOVAL OF COLIFORM BACTERIA BY BAN NONG SUANG LARGE SCALE FILTER UNIT

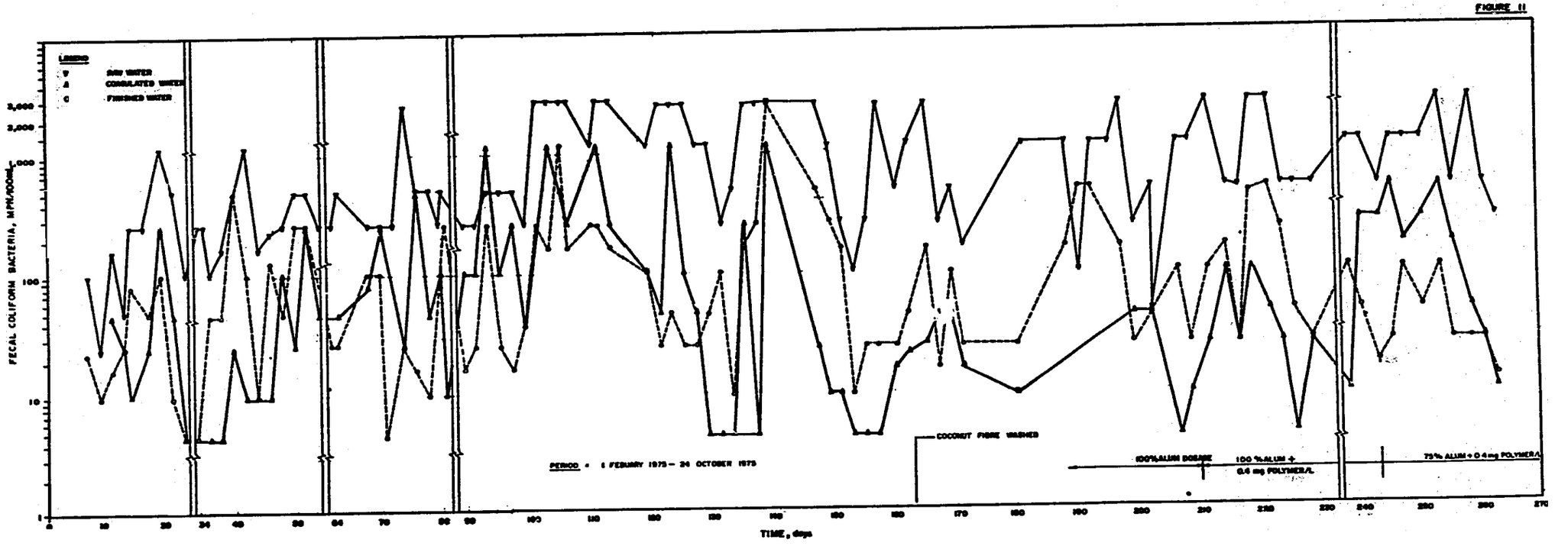


FIGURE II

REMOVAL OF FECAL COLIFORM BACTERIA BY BAN NONG SUANG LARGE SCALE FILTER UNIT

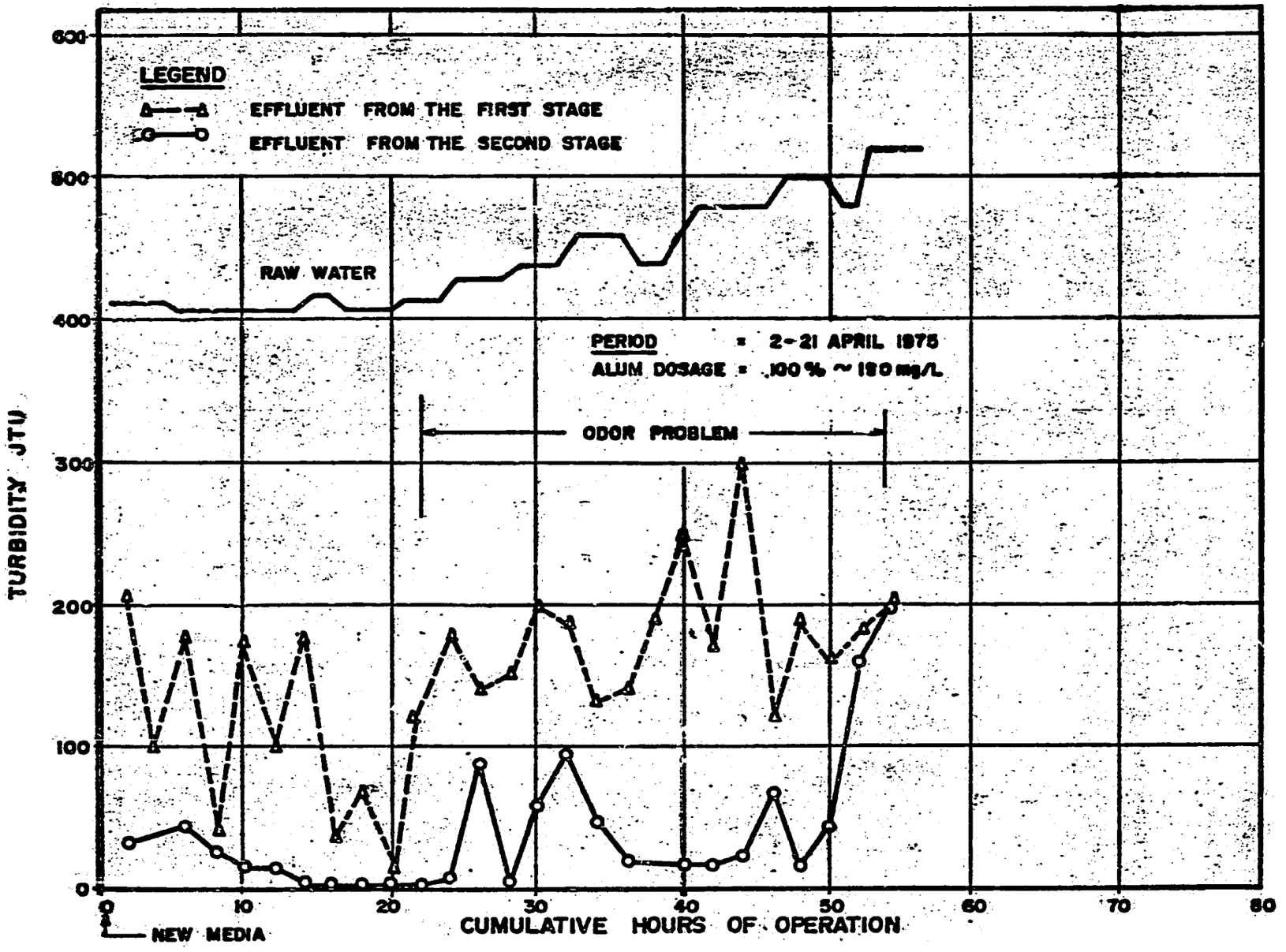


FIGURE 12

TURBIDITY REMOVAL BY THE SMALL TWO STAGE PILOT UNIT AT BAN NONG SUANG

(FILTER RATE 0.24 $m^3/m^2/hr$ RUN NO. 1)

FIGURE 12

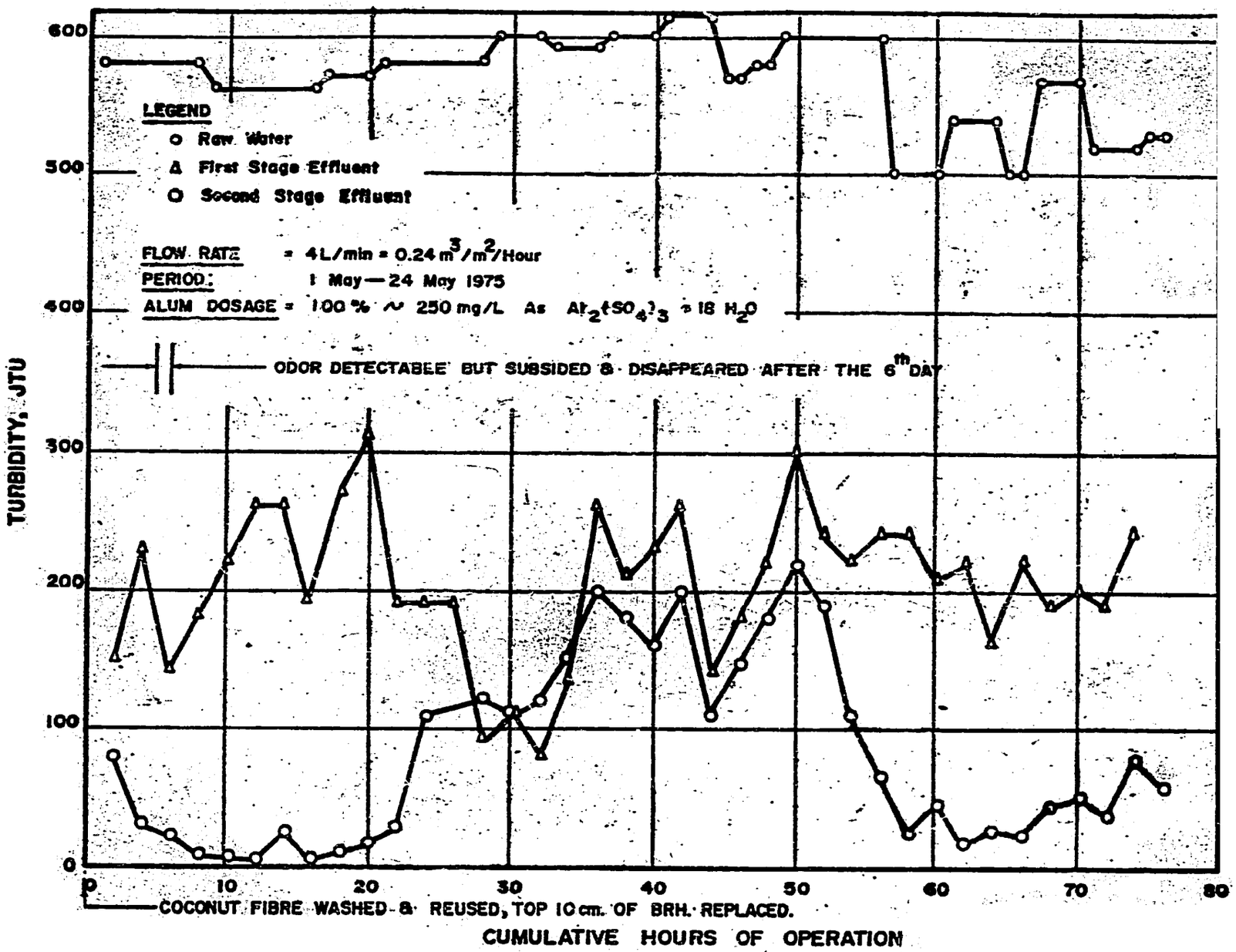


FIGURE 13 TURBIDITY REMOVAL BY THE SMALL PILOT UNIT, BAN NONG SUANG, RATE 0.24 M^3/M^2/HOUR

RUN NO. 2

FIGURE 13

FIGURE 14

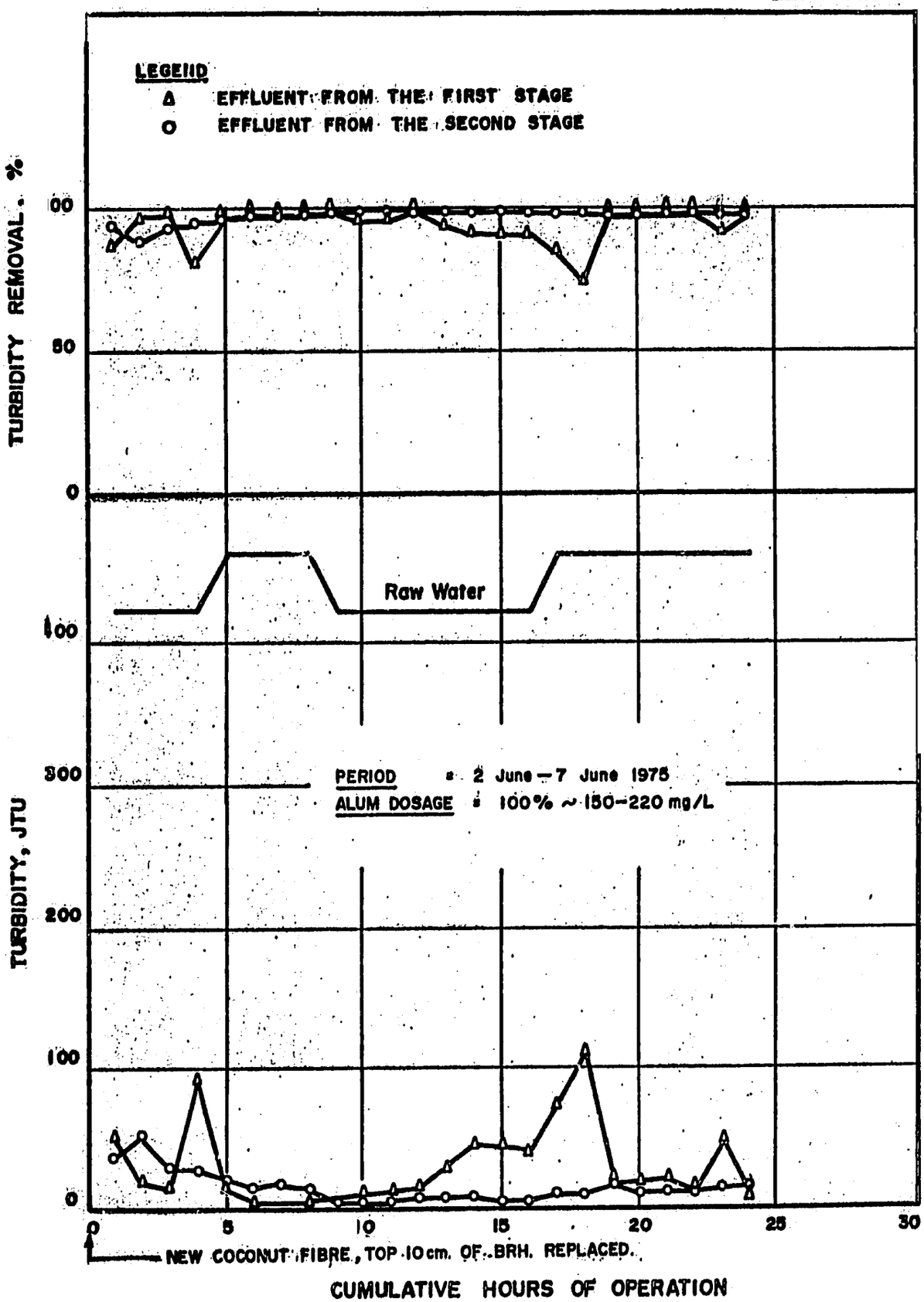


FIGURE 14

TURBIDITY REMOVAL BY THE SMALL PILOT UNIT AT BAN NONG SUANG

RATE 0.24 M^3/M^2/HOUR RUN NO. 3

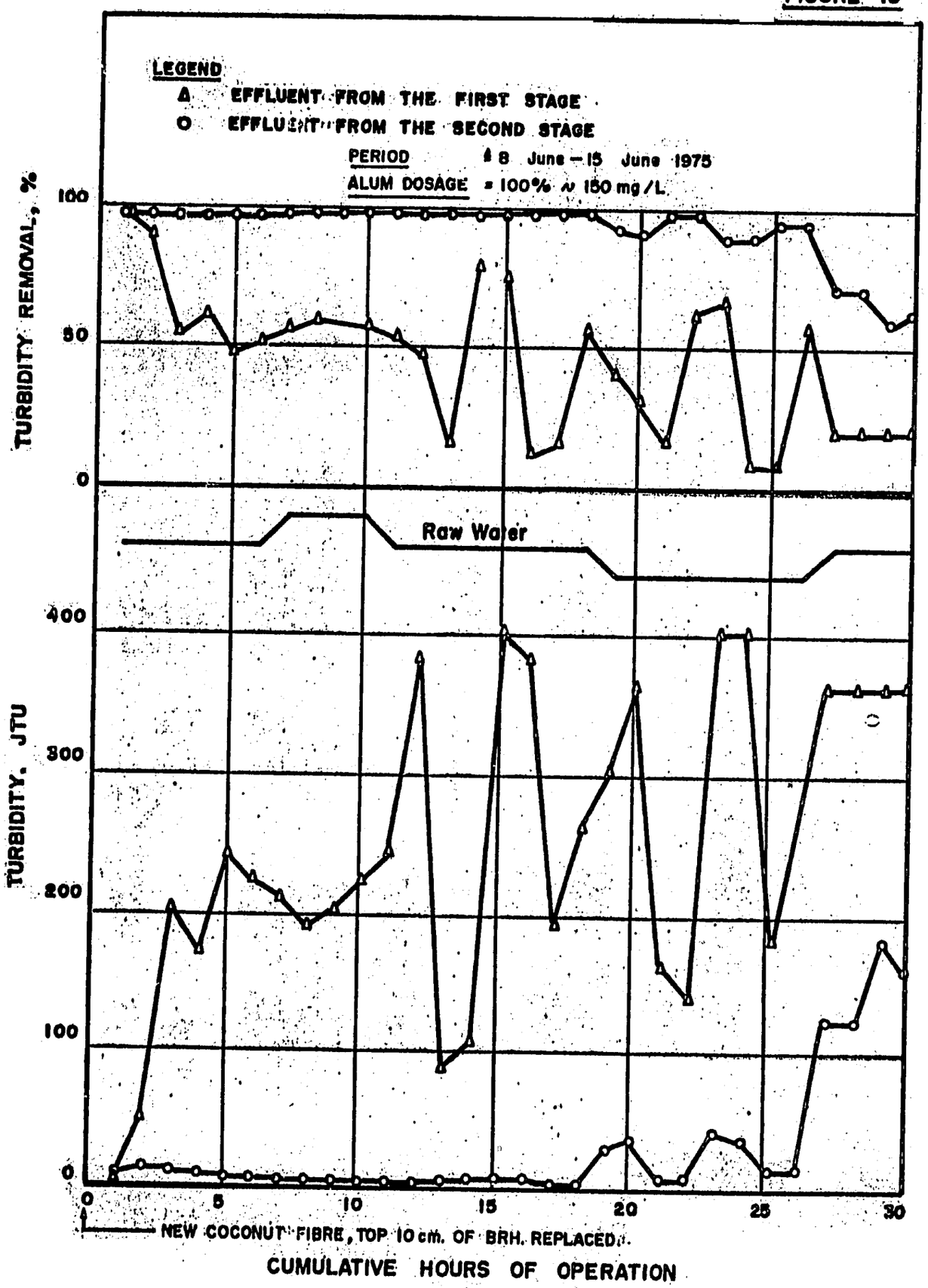


FIGURE 15

TURBIDITY REMOVAL BY SMALL TWO-STAGE PILOT UNIT AT BAN NONG SUANG RATE 0.60 M^3/M^2/HOUR RUN NO. 1

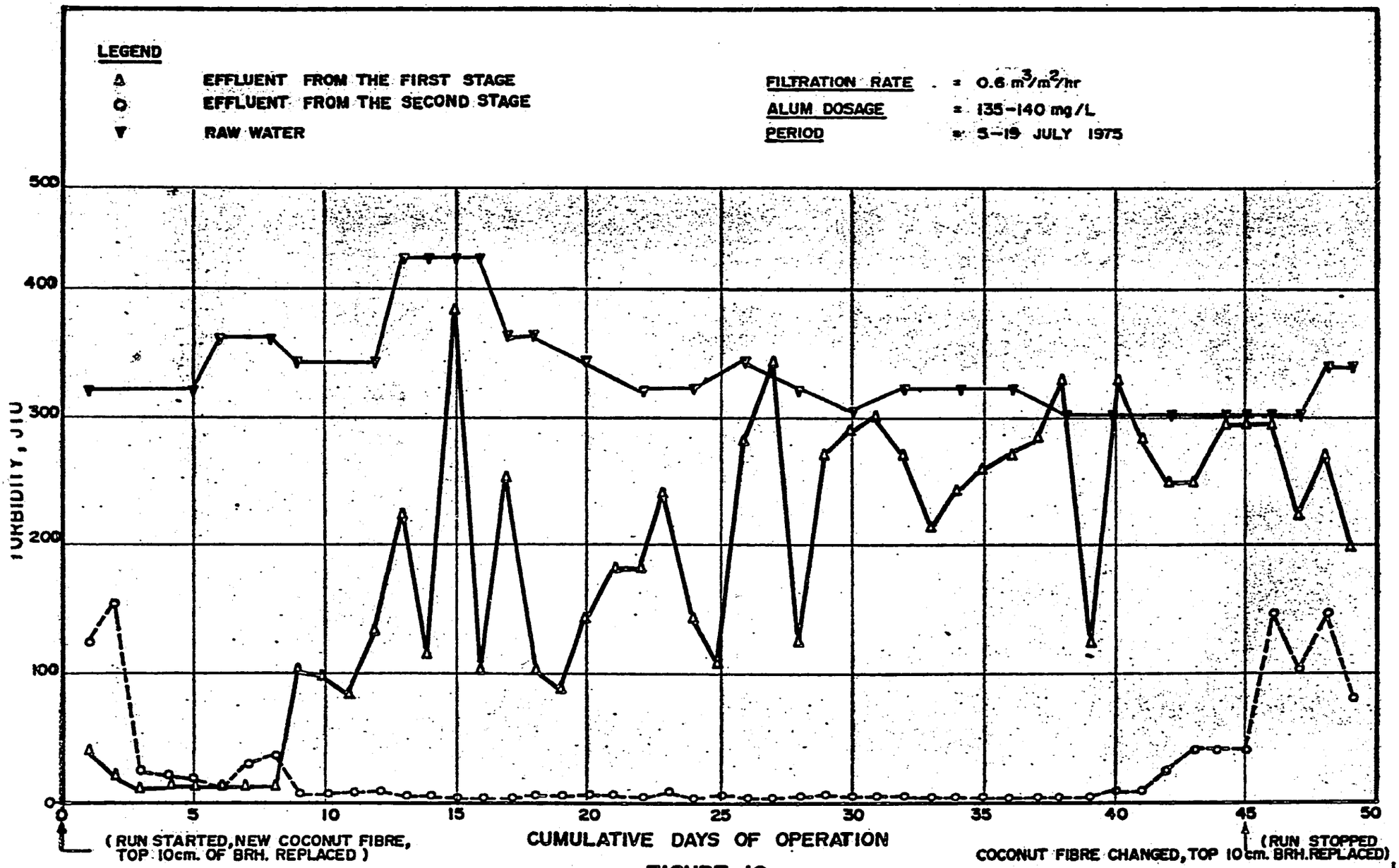


FIGURE 16

REMOVAL OF TURBIDITY USING IMPROVED CONTACT FILTRATION AT BAN NONG SUANG

(RATE 0.60 $m^3/m^2/hr$ RUN NO. 2)

FIGURE 16

FIGURE 17

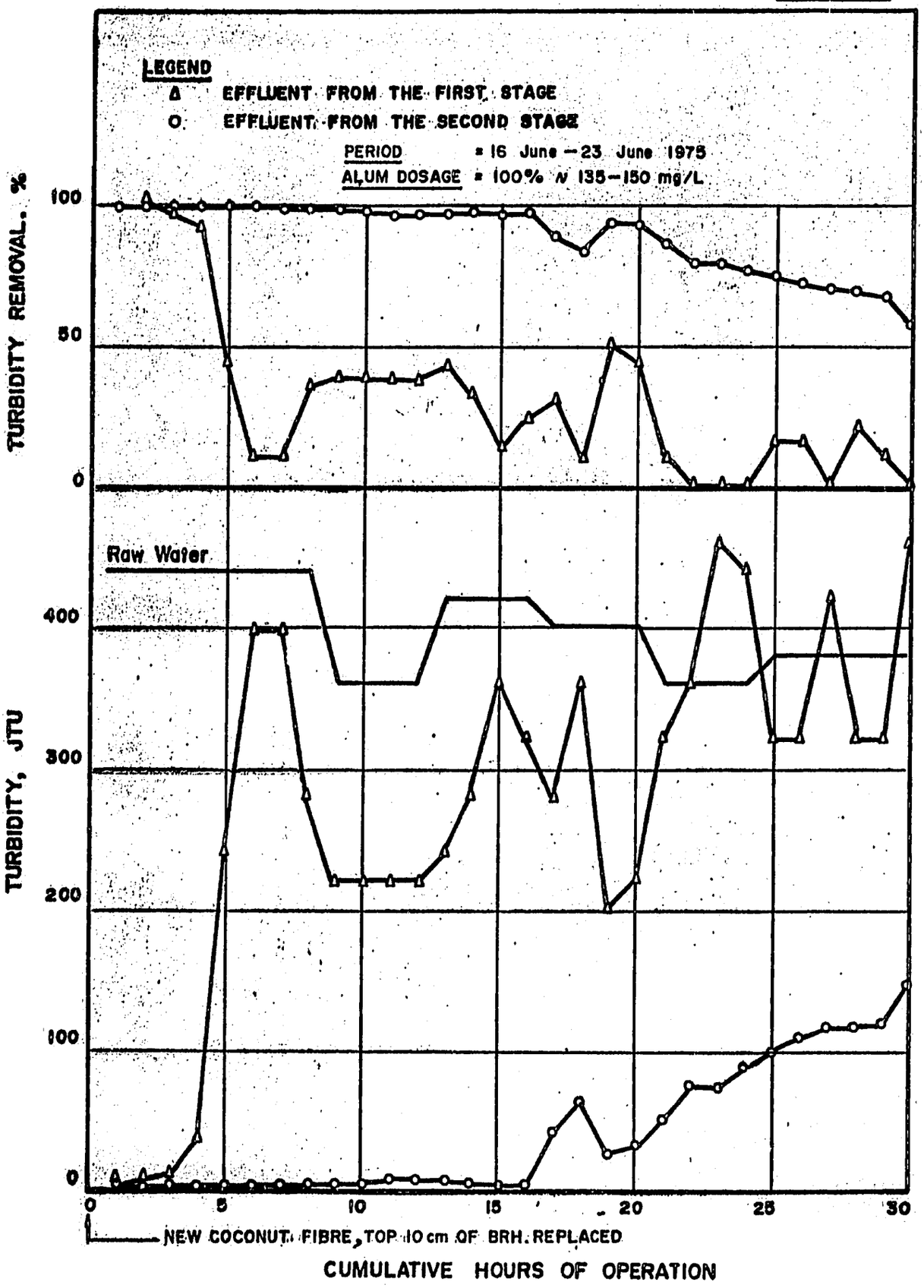
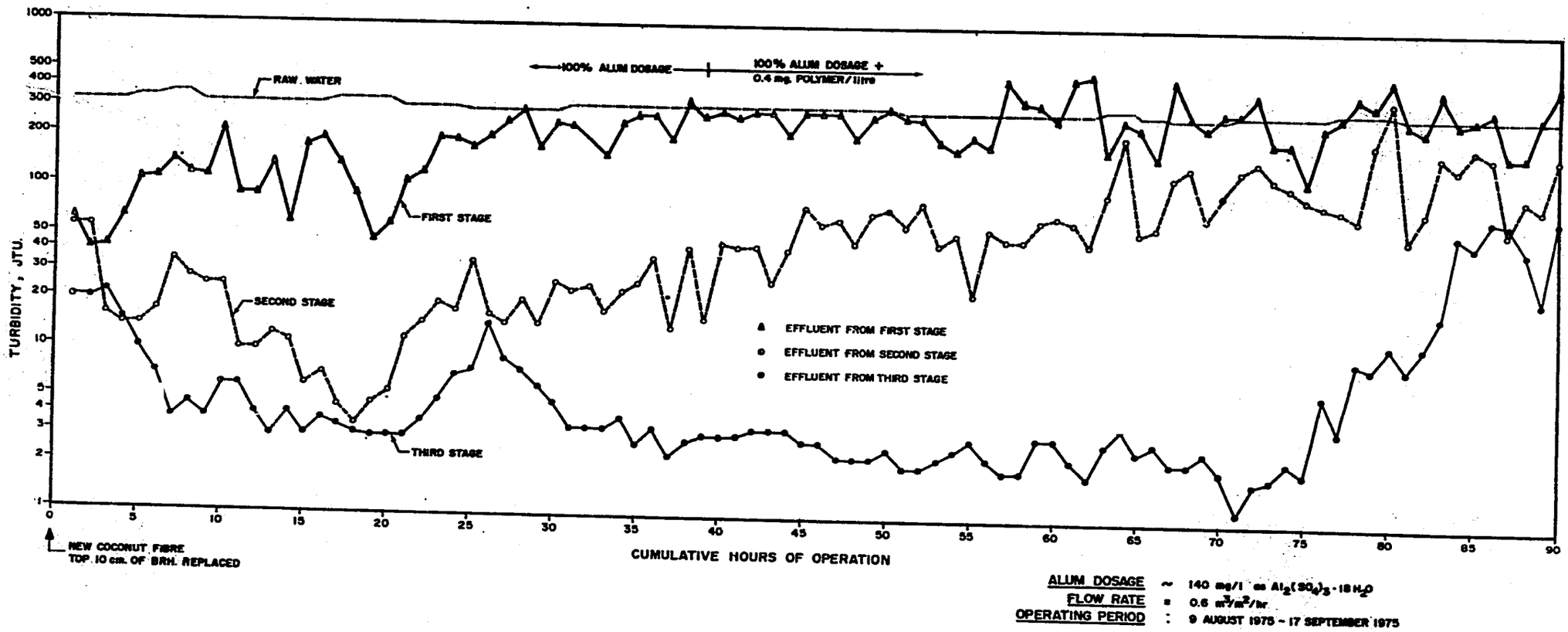


FIGURE 17

TURBIDITY REMOVAL BY THE SMALL TWO-STAGE PILOT UNIT AT BAN NONG SUANG RATE 0.84 M^3/M^2 HOUR

FIGURE 18



ALUM DOSAGE ~ 140 mg/l as $Al_2(SO_4)_3 \cdot 18H_2O$
FLOW RATE = 0.6 $m^3/m^2/hr$
OPERATING PERIOD : 9 AUGUST 1975 - 17 SEPTEMBER 1975

FIGURE 18

REMOVAL OF TURBIDITY USING THREE - STAGE FILTER UNIT AT BAN NONG SUANG

(ALUM DOSAGE AT 100 %)

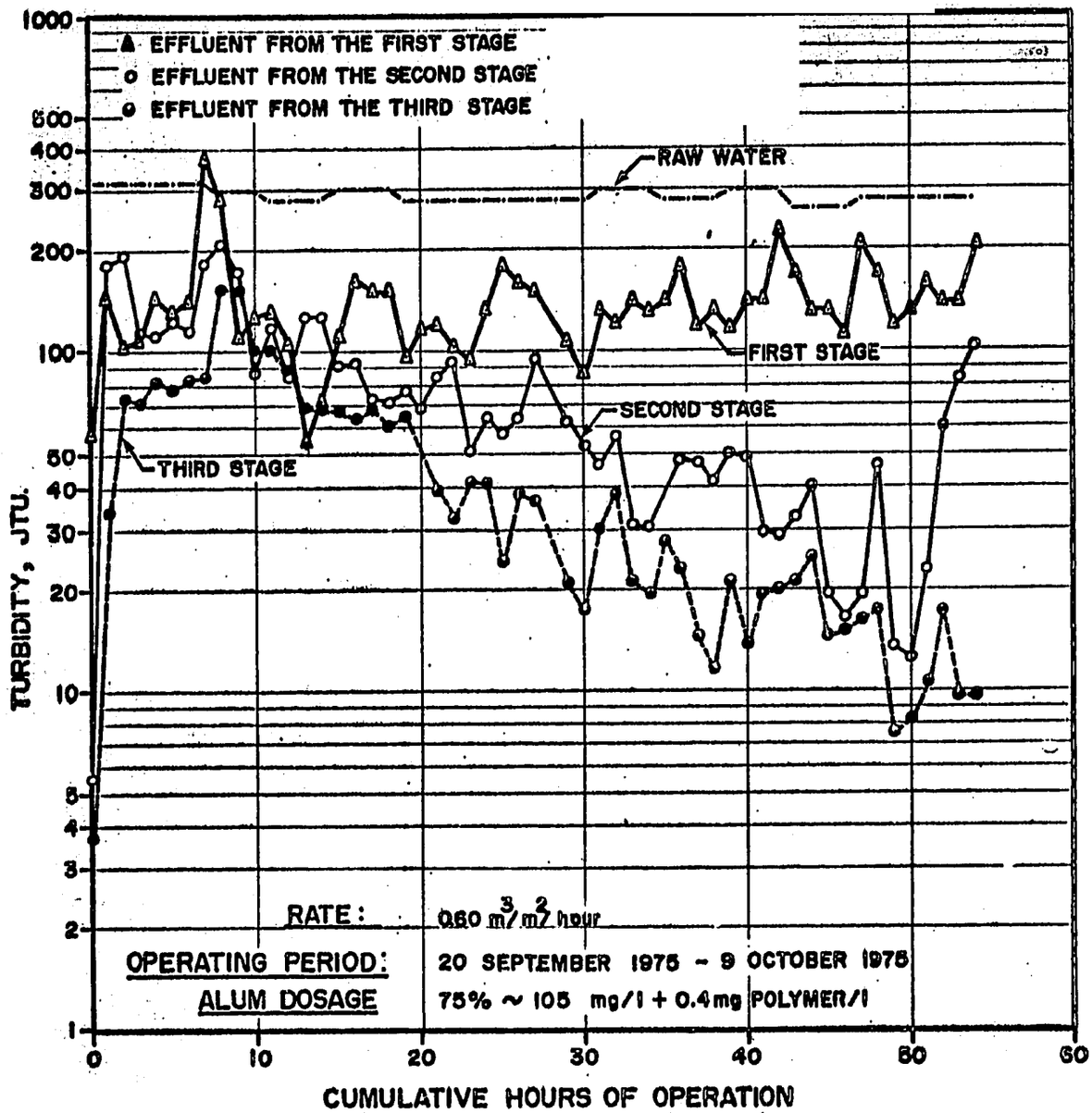


FIGURE 19

REMOVAL OF TURBIDITY BY THE THREE - STAGE PILOT UNIT AT BAN NONG SUANG

FIGURE 20

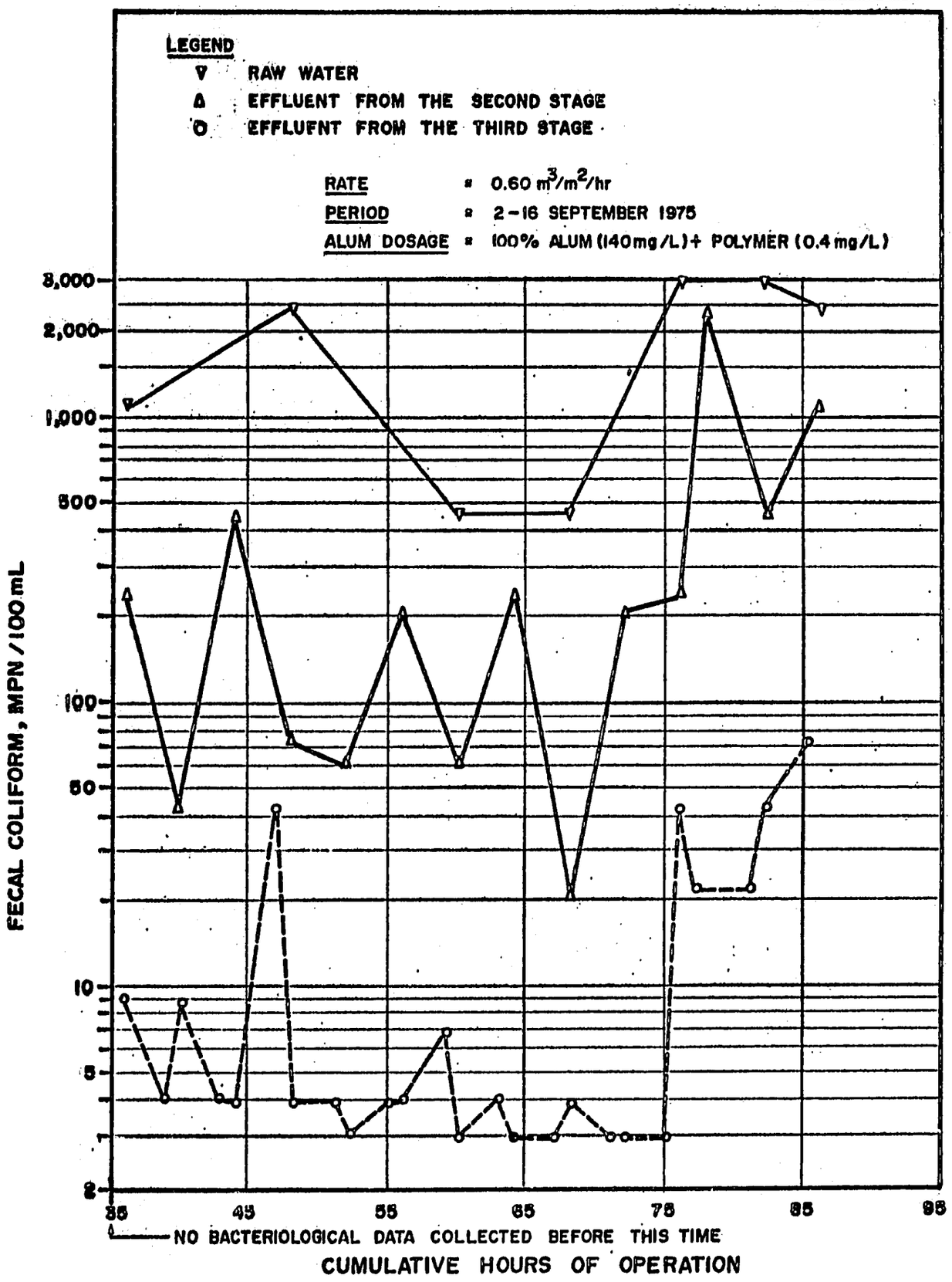


FIGURE 20

REMOVAL OF FECAL COLIFORM BY THREE-STAGE PILOT UNIT AT BAN NONG SUANG

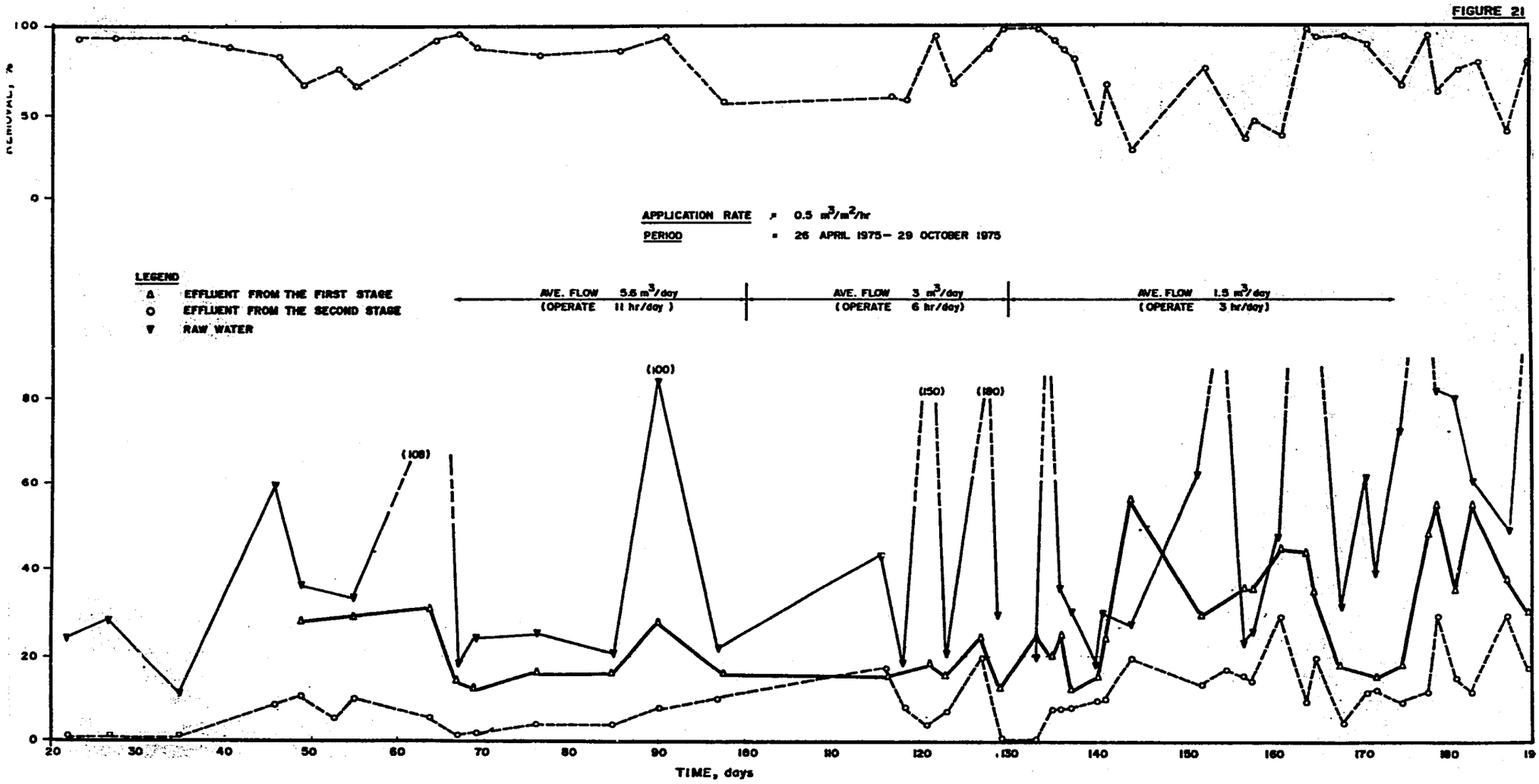


FIGURE 21

TURBIDITY REMOVAL BY THE NONG KHAEM FILTER UNIT, THONBURI

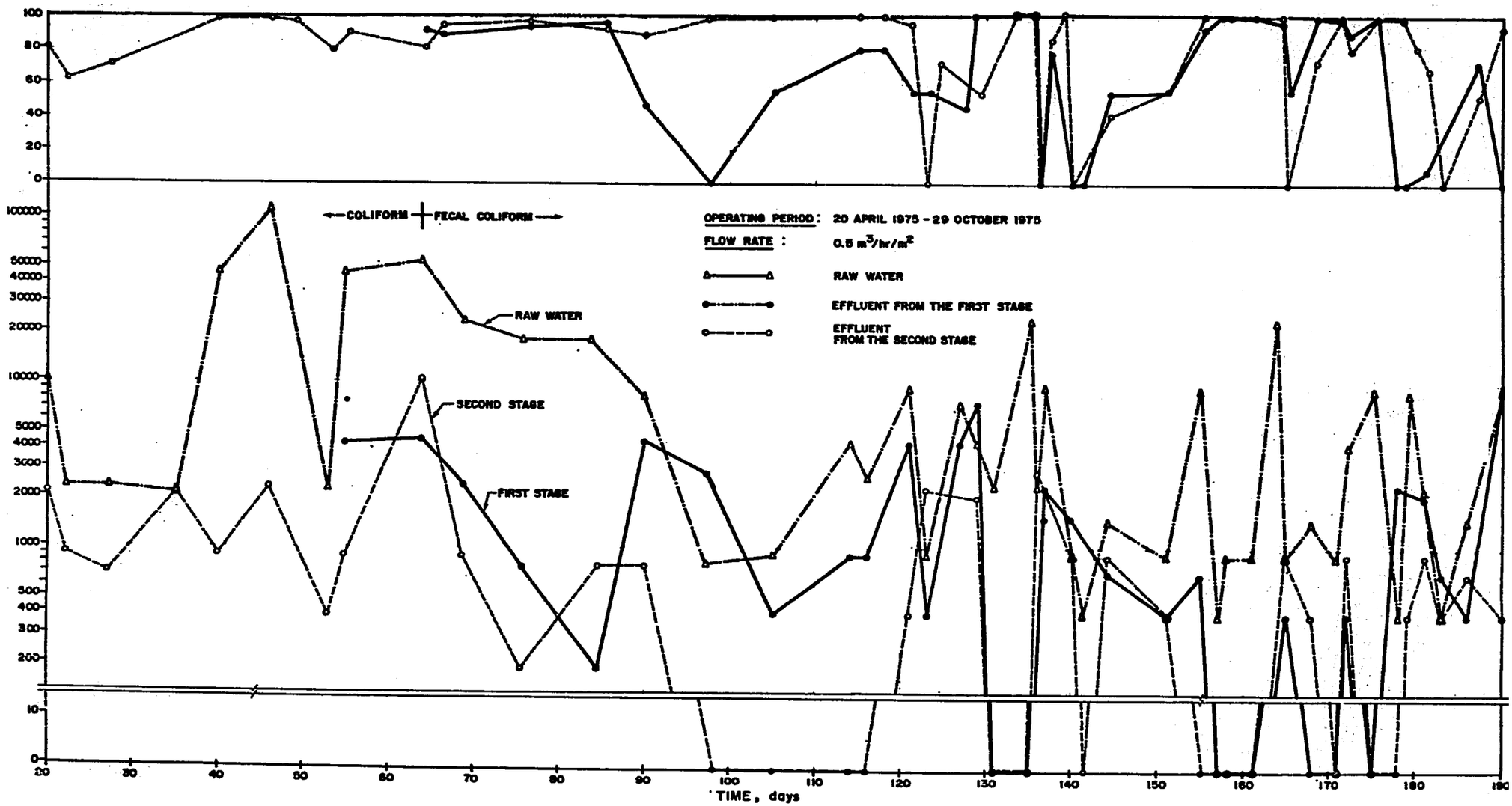


FIGURE 22

BACTERIA REMOVALS BY NONG KHAEM FILTER UNIT

FIGURE 23

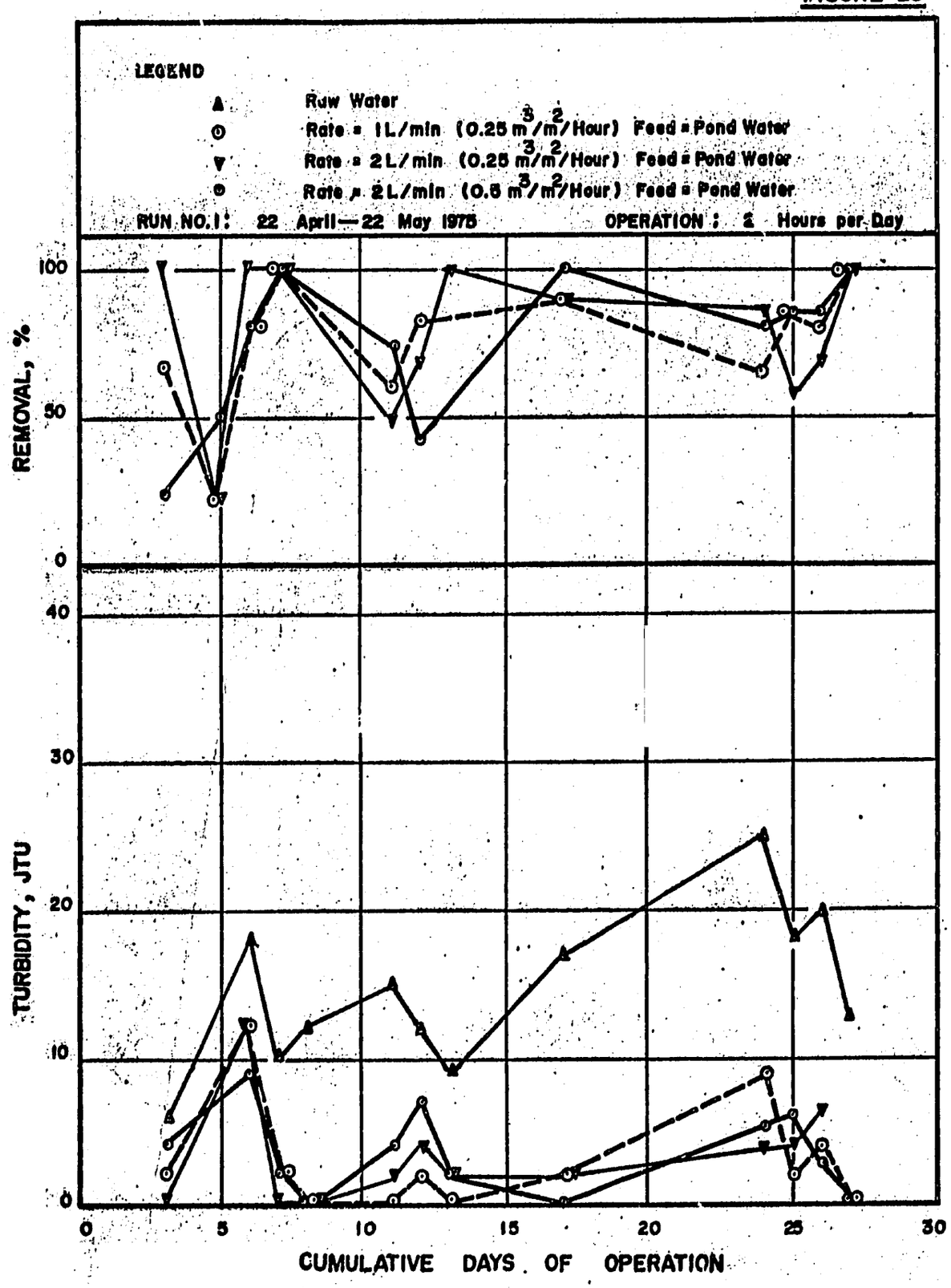


FIGURE 23

TURBIDITY REMOVAL INDIVIDUAL FAMILY SIZE FILTER, RUN NO. 1

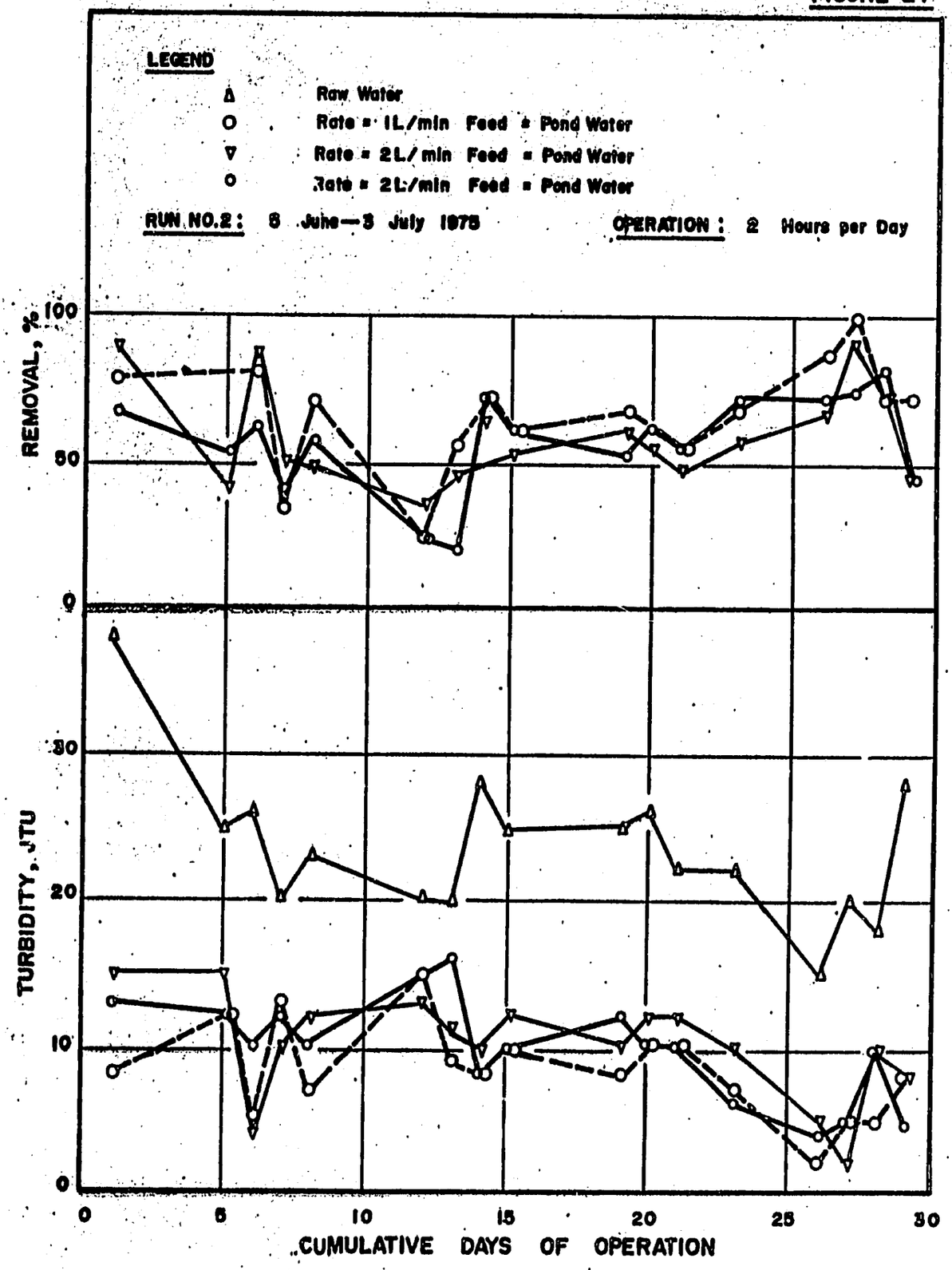


FIGURE 24

TURBIDITY REMOVAL INDIVIDUAL FAMILY SIZE FILTER, RUN NO.2

FIGURE 25

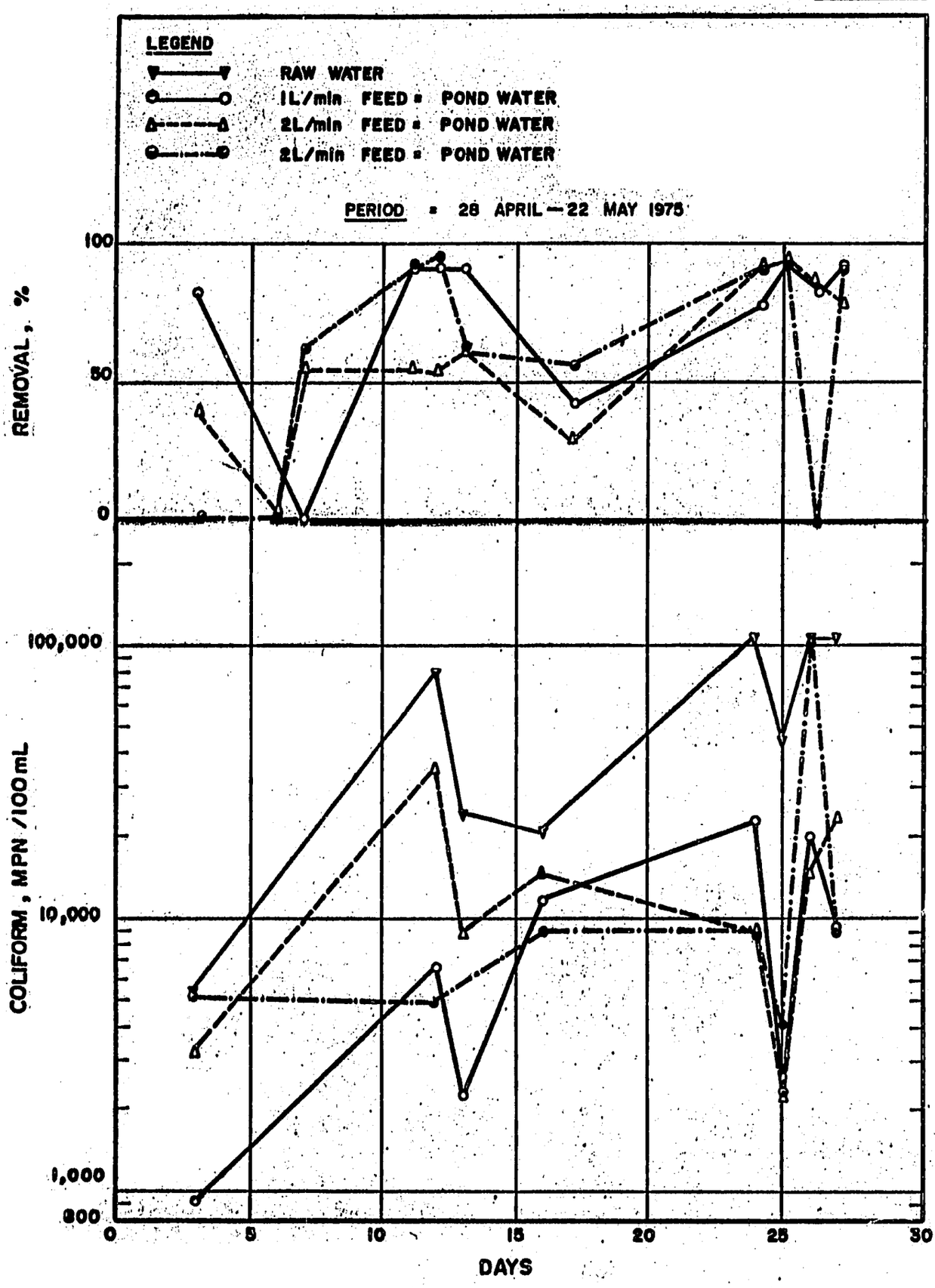


FIGURE 25

COLIFORM REMOVAL BY INDIVIDUAL FAMILY SIZE FILTER, RUN NO. 1

FIGURE 26

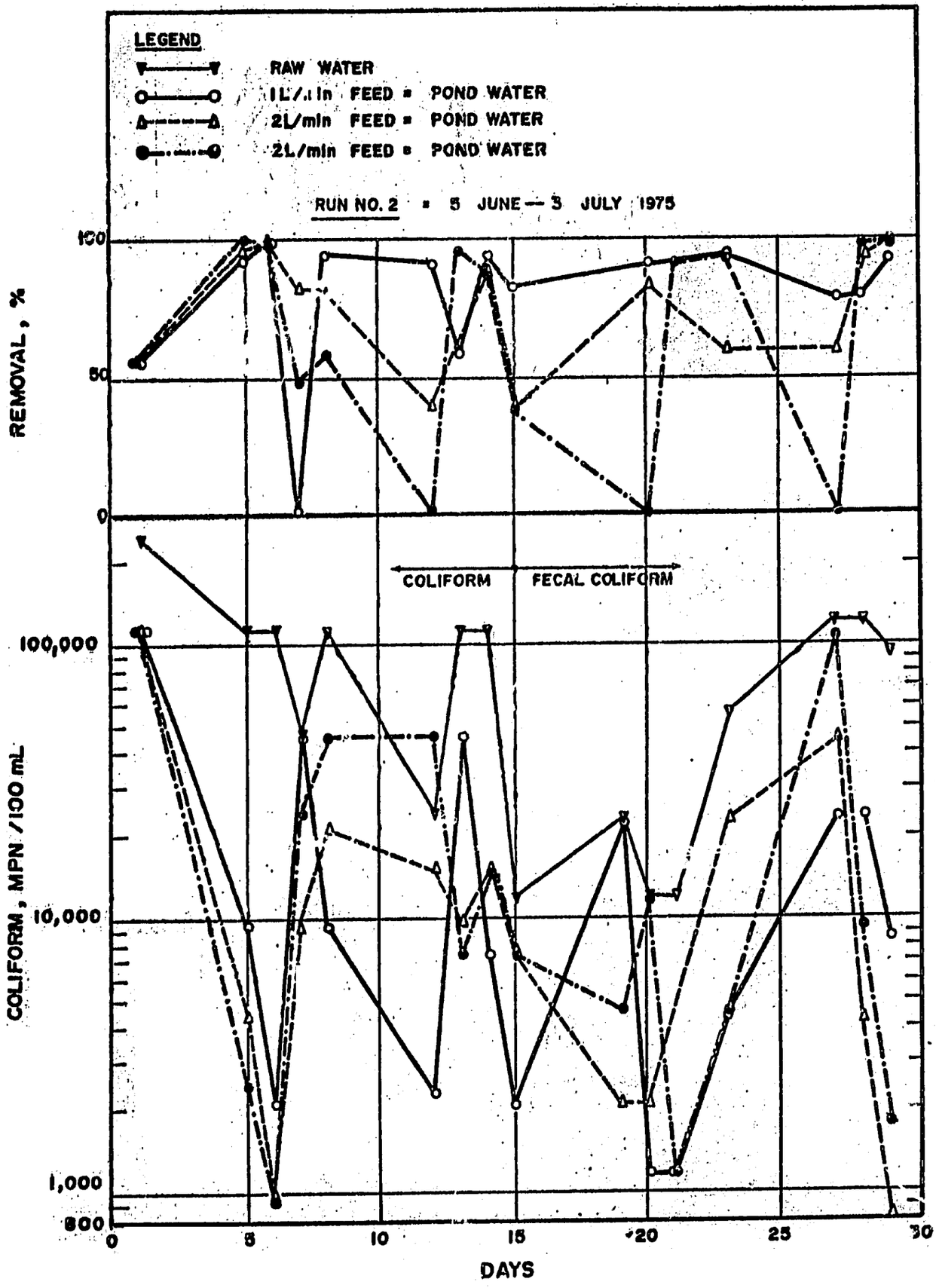


FIGURE 26

COLIFORM REMOVAL BY INDIVIDUAL FAMILY SIZE FILTER, RUN NO.2

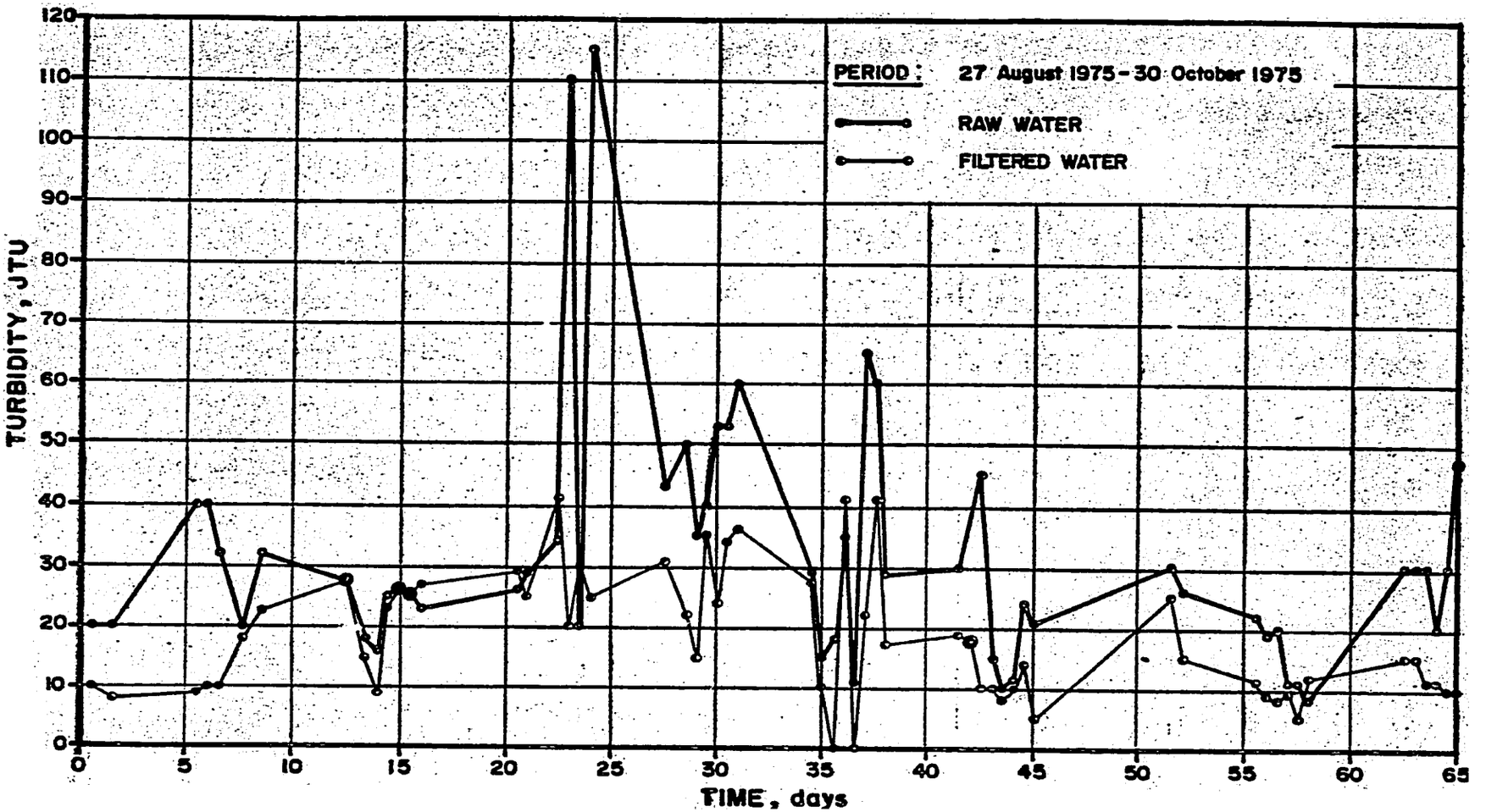


FIGURE 27

TURBIDITY REMOVAL BY INDIVIDUAL FAMILY SIZE FILTER USING WOVEN COCONUT FIBRE MATERIAL

FIGURE 27

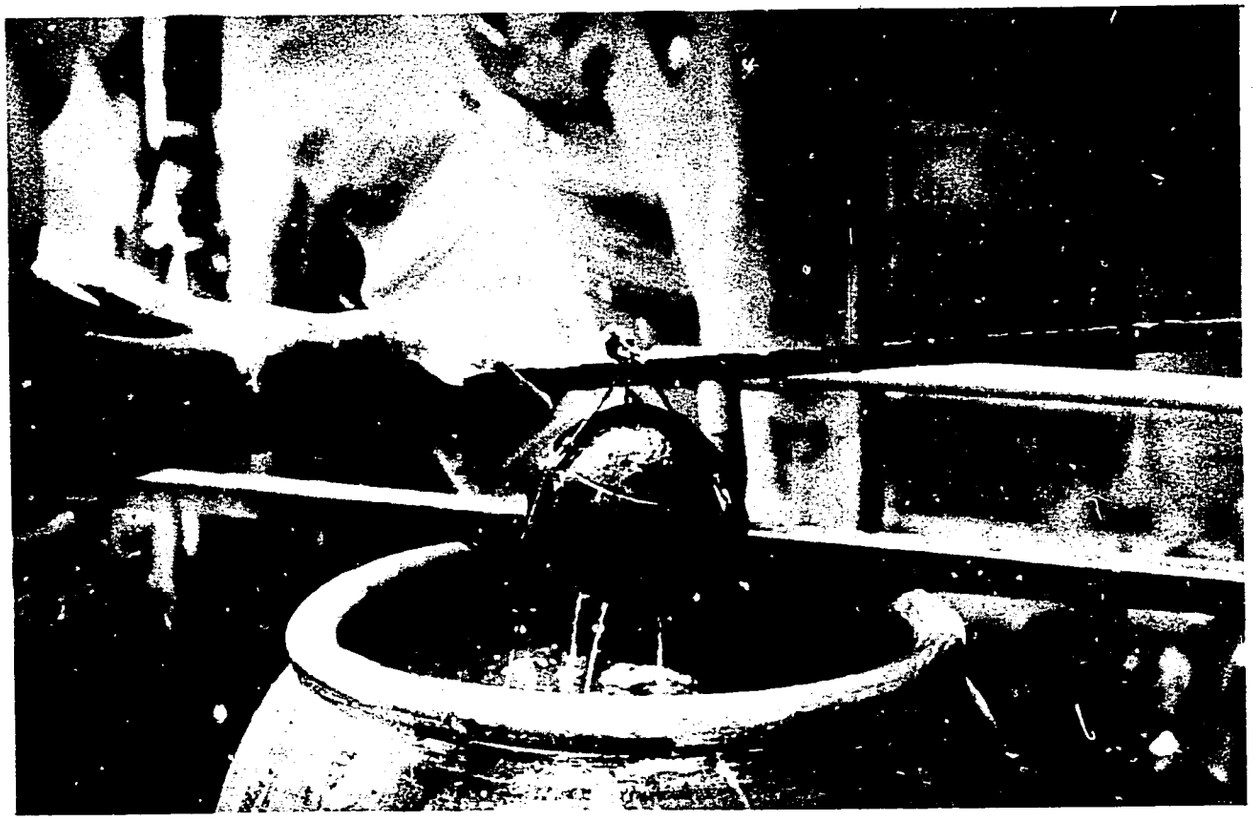


FIGURE 28

PHOTOGRAPH OF SIMPLE COCONUT SHELL CHLORINATOR FOR USE IN INDIVIDUAL FAMILY SIZE JAR FILTER

FIGURE 28

FIGURE 29

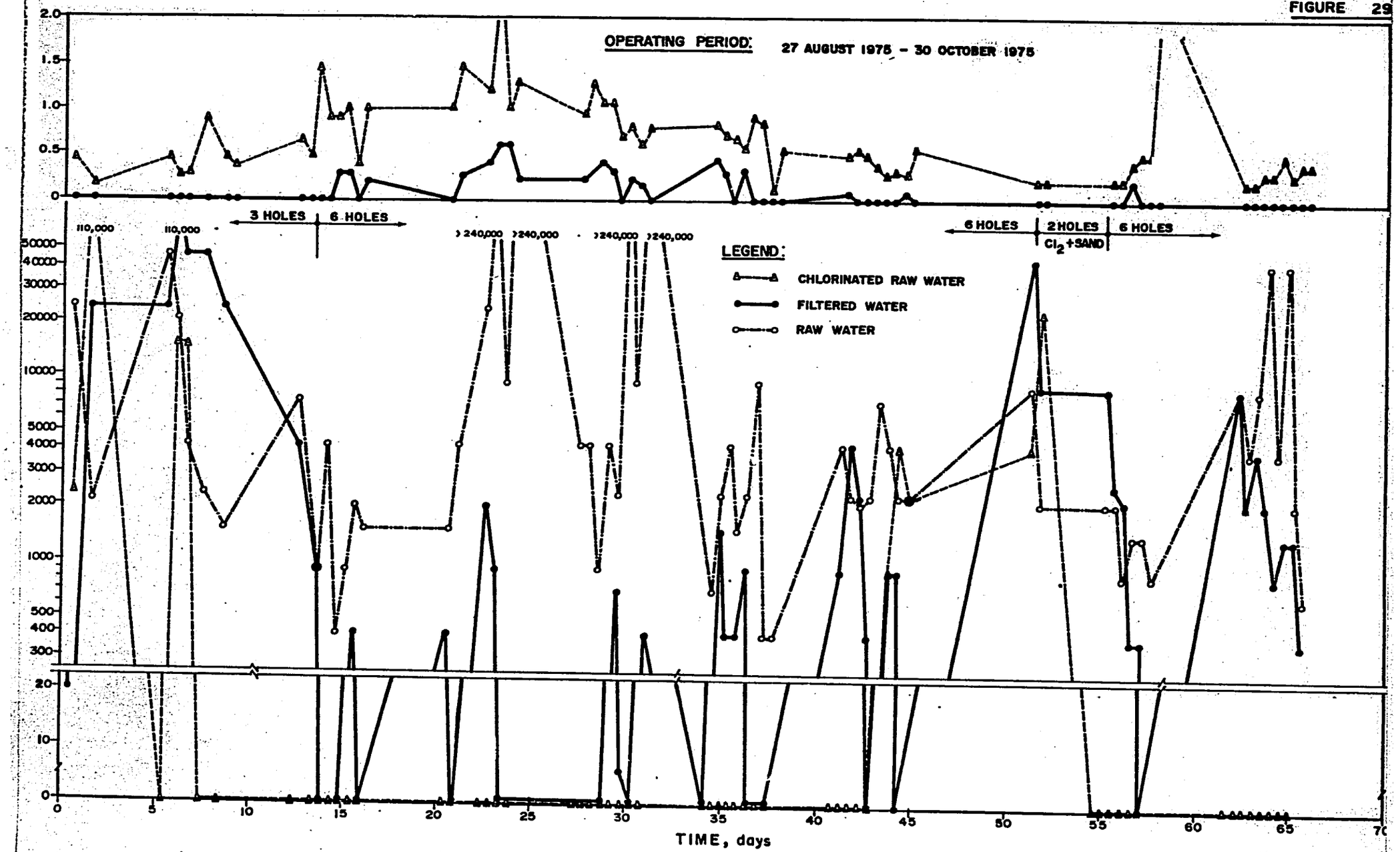

OPERATING PERIOD: 27 AUGUST 1975 - 30 OCTOBER 1975
3 HOLES
6 HOLES
6 HOLES
2 HOLES
Cl_2+SAND
6 HOLES
110,000
110,000
>240,000
>240,000
>240,000
>240,000
LEGEND:
CHLORINATED RAW WATER
FILTERED WATER
RAW WATER
TIME, days

TABLE 1

STATISTICAL ANALYSIS OF BACTERIOLOGICAL DATA USING ALL DATA POINTS

BAN SOM, KORAT PROVINCE

Flow Rate	Statistics	Coliform			Fecal Coliform		
		Raw, MPN/100 ml	Effluent, MPN/100 ml	Removal, %	Raw, MPN/100 ml	Effluent, MPN/100 ml	Removal, %
Normal Rate ($0.8\ m^3/m^2/hr$)	Mean	3,415	961	62	806	269	66
	Standard deviation	3,227	1,523	34	855	576	36
	95% confidence interval of mean 1/	2,659 to 4,171	604 to 1,318	54 to 70	606 to 70	134 to 404	58 to 74
	95% confidence interval of variable 2/	0 to 9,860	0 to 4,007	0 to 100	0 to 2,516	0 to 1,421	0 to 100
	Number of data points	70	70	70	70	70	70

Statistical Inference:

The differences in bacteria content in the final effluent at the two flow rates are not statistically significant for either coliform or fecal coliform.

Notes:

1/ 95% confidence interval of mean $= \bar{x} \pm 1.96 \frac{S}{\sqrt{N}}$

2/ 95% confidence interval of variable $= \bar{x} \pm 1.96\ S$

$\bar{x}$ = mean S = standard deviation N = number of data points

TABLE 1

TABLE 2

STATISTICAL ANALYSIS OF BACTERIOLOGICAL DATA USING SELECTED DATA POINTS

BAN SOM, KORAT PROVINCE

Flow Rate	Statistics	Coliform			Fecal Coliform		
		Raw, MPN/100 ml	Effluent, MPN/100 ml	Removal, %	Raw, MPN/100 ml	Effluent, MPN/100 ml	Removal, %
Normal rate ($0.8\ m^3/m^2/hr$)	Mean	3,783	623	76	888	139	82
	Standard deviation	3,334	603	18	880	229	18
	95% confidence interval of mean	2,918 to 4,648	467 to 779	71 to 81	655 to 1,221	74 to 204	77 to 87
	95% confidence interval of variable	0 to 10,450	0 to 1,829	40 to 100	0 to 2,548	0 to 597	60 to 100
	Number of data points	57	57	57	57	57	57
High rate ($1.2\ m^3/m^2/hr$)	Mean	4,446	503	82	783	107	80
	Standard deviation	5,149	530	11	798	110	20
	95% confidence interval of mean	2,504 to 6,388	302 to 702	78 to 86	463 to 1,102	64 to 150	72 to 88
	95% confidence interval of variable	0 to 14,740	0 to 1,563	60 to 100	0 to 2,380	0 to 327	40 to 100
	Number of data points	27	27	27	25	25	25

Statistical Inference:

The differences in bacteria content in the final effluent at the two flow rates are not statistically significant for either coliform or fecal coliform.

Note:

Data points where effluent bacteria $\geqslant$ influent bacteria levels were not included in above statistical tests.

TABLE 3

STATISTICAL ANALYSIS OF BACTERIOLOGICAL DATA USING ALL DATA POINTS

BAN NONG SUANG, KORAT PROVINCE

Statistics	Coliform					Fecal Coliform				
	Raw MPN/100 ml	Coagulated Water		Finished Water		Raw MPN/100 ml	Coagulated Water		Finished Water	
		MPN/100 ml	Removal, %	MPN/100 ml	Removal, %		MPN/100 ml	Removal, %	MPN/100 ml	Removal, %
Maximum	>24,000	11,000	100	> 24,000	100	> 2,400	1,100	100	>2,400	99
Minimum	430	<30	28	30	37	93	<3	49	<3	38
Mean	8,920	2,004	74	1,427	77	973	147	83	143	83
Standard deviation	7,782	2,968	29	2,723	29	864	277	24	282	21
95% Confidence interval of mean	7,417 to 10,423	1,434 to 2,574	68 to 80	901 to 1,953	71 to 83	827 to 1,119	98 to 196	79 to 87	94 to 193	79 to 87
95% Confidence interval of variable	0 to 24,480	0 to 7,940	16 to 100	0 to 6,873	19 to 100	0 to 2,700	0 to 700	35 to 100	0 to 707	41 to 100
Number of data points	103	97	97	103	103	134	122	122	134	134

Inference: Test differences of means for coagulated water and finished water

1. Coliform (a) MPN: Not statistically significant
   (b) % Removal: Not statistically significant
2. Fecal Coliform (a) MPN: Not statistically significant
   (b) % Removal: Not statistically significant

TABLE 3

TABLE 4

STATISTICAL ANALYSIS OF BACTERIOLOGICAL DATA USING SELECTED DATA POINTS

BAN NONG SUANG, KORAT PROVINCE

Statistics	Coliform					Fecal Coliform				
	Raw	Coagulated Water		Finished Water		Raw	Coagulated Water		Finished Water	
	MPN/100 ml	MPN/100 ml	Removal, %	MPN/100 ml	Removal, %	MPN/100 ml	MPN/100 ml	Removal, %	MPN/100 ml	Removal, %
Maximum	>24,000	11,000	100	4,600	100	≥2,400	1,100	100	1,100	99
Minimum	430	<30	28	30	37	93	<3	49	<3	38
Mean	9,468	1,690	80	953	85	1,043	129	88	115	86
Standard deviation	7,826	2,587	21	1,010	17	886	253	14	188	15
95% Confidence interval of mean	7,851 to 11,085	1,140 to 2,240	76 to 85	744 to 1,162	82 to 89	889 to 1,197	83 to 175	85 to 91	82 to 147	83 to 88
95% Confidence interval of variable	0 to 25,120	0 to 6,864	38 to 100	0 to 2,973	51 to 100	0 to 2,815	0 to 635	60 to 100	0 to 491	56 to 100
Number of data points	90	85	85	90	89	127	115	114	126	127

Inference: Test differences of means for coagulated water and finished water

1. Coliform (a) MPN: Statistically significant
   (b) % Removal: Not statistically significant
2. Fecal Coliform (a) MPN: Not statistically significant
   (b) % Removal: Not statistically significant

TABLE 4

TABLE 5

COMPARISON OF LARGE SCALE AND SMALL SCALE FILTER UNITS AT BAN NONG SUANG, KORAT PROVINCE

Parameter	Large Scale Unit	Small Scale Unit	
		Two-Stage	Three-Stage
Surface area of media, m^3	10	1.0	1.5
Filtration rate, $m^3/m^2/hr$	0.5	0.6	0.6
Length of filter run (approx.), hr	450	31	75
Water produced, $m^3/run/10\ m^2$	2,250	186	300
Turbidity load to filter, % of raw	5	100	100
Maximum water producable, m^3/day	20	>50	>50
Construction cost	High	Low	Low
Construction	Difficult	Easy	Easy
Operation attention	Low	Moderate (mostly media washing)	Moderate (mostly media washing)