FEASIBILITY STUDY ON THE UTILIZATION OF U.S. TECHNOLOGIES FOR ARSENIC REMOVAL OF DRINKING WATER IN HUNGARY

Task C

Evaluation of Pilot Plant Tests

C.4-1 Hungerford & Terry's Pilot Plant

INDEX:

1.Chronology and Pilot Plant Test Sites ... 3

2.General Characteristics of Pilot Plant Tests ... 3

3.Operation of the Pilot Plant ... 4

4.Pilot Test Run At Orgovány ... 6

4.1General Description ... 6
4.2Main Service Run Data ... 7
4.2.1Volume of Water ... 7
4.2.2Chemical Feeding ... 7
4.2.3Data of Water Quality Analysis ... 8
4.2.4Waste Water Quality ... 10

5.Pilot Test Run At Szeghalom ... 10

5.1General Description ... 10
5.21st Test Period (Influent Water: Pre-treated Water) – Main Service Run Data ... 12
5.2.1Volume of Water ... 12
5.2.2Chemical Feeding ... 12
5.2.3Data of Water Quality Analysis ... 13
5.2.4Waste Water Quality ... 14
5.32nd Test Period (Influent Water: Well Water) – Main Service Run Data ... 16
5.3.1Volume of Water ... 16
5.3.2Chemical Feeding ... 17
5.3.3Data of Water Quality Analysis ... 18
5.3.4Waste Water Quality ... 19

6.Summation of Pilot Plant Tests ... 19

ANNEX

1.1 Water Quality Analysis in Orgovány
by the Central Laboratory of BÁCSVÍZ Co. (Table)

1.2. On-Site Water Analysis Data in Orgovány (Table)

1.3.1 As Content Run in Orgovány
by the Central Laboratory of BÁCSVÍZ Co. (Table)

1.3.2 As Content Run in Orgovány
by the Central Laboratory of BÁCSVÍZ Co. (Graph)

1.4.1 Waste Water Quality Data in Orgovány (Table)

1.4.2 Settling Curve of Waste Water in Orgovány (Graph)

2.1 Water Quality Analysis in Szeghalom
by the Central Laboratory of Békés County Waterworks Co. (Table)

2.2.1 On-Site Water Analysis Data in Szeghalom
Influent Water: Pre-treated, Chlorinated Water (table)

2.2.2 On Site Water Analysis Data in Szeghalom
Influent Water: Water From the Well # II./3 (Table)

2.3.1.1 As Content Run in Szeghalom I.
Influent Water: Pre-treated, Chlorinated Water (Table)

2.3.1.2 As Content Run in Szeghalom I. – On the Basis of On-Site Analysis
Influent Water: Pre-treated, Chlorinated Water (Graph)

2.3.2.1 As Content Run in Szeghalom II.
Influent Water: Water From the Well # II./3 (Table)

2.3.2.1 As Content Run in Szeghalom II. – On the Basis of On-Site Analysis
Influent Water: Water From the Well # II./3 (Graph)

2.4 Waste Water Quality Data in Szeghalom (Table)

3. Water Analysis Data by the OKK-OKI Laboratory (Table)

1.CHRONOLOGY AND PILOT PLANT TEST SITES

The experiment was conducted at Orgovány, from December 10 to 22, 2003, then continued at the Szeghalom local waterworks plant, from January 6 to 20, 2004.

There is presently no water treatment at Orgovány. Water is drawn from two wells and fed in a co-ordinated way, to a network with a counter-press system and a water tower. This is conducted according to water demands. The quality of raw water and the conditions of operation have allowed for raw well water to get to consumers without decontamination.

The well water is purified at Szeghalom (removal of iron- and manganese, as well as arsenic, by rapid coagulation technology, ammonium removal by breaking point chlorination, dechlorination using activated carbon filtration), and decontaminated, prior to transmission to the network.

2.GENERAL CHARACTERISTICS OF PILOT PLANT TESTS

The samplings and water quality analyses have been conducted beginning with the start-up of the plant, partly meeting the requirements of the supplier, and partly in an order according to the pilot plant plan, adjusted to the operation of the equipment. There have been water quality investigations performed at the two designated sites, in the central laboratories of the waterworks, and also in the laboratory of the National Institute for Environmental Health, operating within the framework of "József Fodor" National Center for Environmental Health (OKK-OKI), partly according to the requirements of the technical facilities for certain water quality measurements.

Data was recorded on-site – this included the results of the local water quality measurement. The data was noted by filling in the sheets of the pilot plant records previously made. A plant operator performed the daily investigation and also noted his/her actions. The general data of plant operation and remarks and operator's interventions have been recorded in the operating diary, while results of local water quality measurements have been recorded in charts specifically for this purpose. The results from the central laboratories of the waterworks and the OKK-OKI laboratory have been summarised by laboratory co-workers. These results are recorded on personal score-sheets and Excel tables, respectively.

Local water quality investigations have been performed as a requirement. These investigations were conducted in order to study the following:

1. The removal of arsenic, iron and manganese from the feed water and consequently its filtering capacity.
2. The build up of pressure drop across the filter, as well as the residual free chlorine content of the treated water.

The chemicals required for the experiments were purchased by the two waterworks from various places. The same chemicals were used in both stages of experiments conducted at Szeghalom. Main parameters of chemicals:

at Orgovány:

Name	Iron (III) chloride 6-hydrate	sodium hypochlorite
Make	Reanal Co. (Hungary)	
State of matter	solid, lumpy	Liquid
Packing	plastic jar	Plastic can
Packed quantity	1 kg	20 l
Agent content	97,0-102,0 %	150 gCl_2/l
Required quantity	for 1 mg/l specific Fe dosing: 4.85 mg	for 1 mg/l specific Cl dosing: 0.007 ml

at Szeghalom:

Name	Iron (III) chloride 6-hydrate	sodium hypochlorite
Make	AKZO NOBEL EKA (Sweden)	Borsodi Vegyi Művek, Kazincbarcika (Hungary)
State of matter	Medimpex Trading Co.	
Packing	Solid	liquid
Packed quantity	paper box	plastic tank
Agent content	100 kg	50 l
Required quantity	min. 98 %	100 gCl_2/l
	for 1 mg/l specific Fe dosing: 4.85 mg	for 1 mg/l specific Cl dosing: 0.01 ml

The preparation and dosing of the chemical solvents have stayed consistent as a function of the quality of water to be treated and the capacity of the feeding pumps available.

3.OPERATION OF THE PILOT PLANT

The equipment has been essentially operated by rapid coagulation technology. First, some oxidant (sodium hypochlorite), then coagulating agent (iron chloride) must be added to the raw water, then filtered on a filter with a double-layer. The double layer filters iron and manganese precipitates from the water, and consequently, arsenate adsorbed on the surface of the iron floc. The primary task of sodium hypochlorite is to oxidize the arsenite content of the water to arsenate, and to oxidize any ferrous iron in the raw water to the ferric state. Arsenate bonds more effectively with precipitated iron.

The filter is charged with a double layer, the lower part being greensand, coated with manganese oxides, while the upper being anthracite.

The chemical feeding pumps were supplied by the equipment vendor. They were machines operating in a peristaltic principle, with rpm to be adjusted free from stages. Since there was no curve of character available during the first adjustment, the transport capacity of the pumps had to be measured for feeding the chemicals. Following this, chemical consumption was monitored during operation, which served as a basis for the determination of the feeding value and the adjustment of the machines for improvement.

The dilution rate of the chemical solutions was determined and the amount of chemicals to be fed was adjusted on the basis of the values of the respective quality parameters of raw water. They were measured at the start of the pilot plant according to the instructions of H&T, as well as the formula for calculation given therein.

> According to the instructions of H&T, it had to be achieved, by adding iron-chloride, so that the Fe:As ratio in the water to be treated was 40:1. This was done together with the iron content originally being present in the water. Furthermore, the feeding of chlorine had to be adjusted, so that the free chlorine content in the effluent water was 0.5-1.0 mg/l. (This essentially means chlorination over breaking point, which has ensured ammonium release of water, on the one hand; while guaranteed continuous maintenance of the oxidative state on the filtering matter, as pre-condition of plant operation, on the other.)

The parameters of the chemicals and their solutions, as well as the amounts fed can be determined from records. (Unfortunately, operator's records were not always correct or precise; therefore, the yield of feeding could not be directly and precisely calculated in every case. Consequently, we also had to rely on oral publications of data, personal records and experience when evaluating data.)

Chemicals were fed from cylindrical, transparent, plastic tanks of 15 gallons (with 56.8 litres), supplied by H&T. The basic area of the tanks was 9.026 dm^2, and the water column had a cubic content of 15 gallons, standing 63 cm high. Similarly, solutions to be fed were also diluted in these tanks.

During standard filtering operation, the equipment always operated with a value set to a water output of 3.5 gpm (13.25 l/min); during backwash, a water output of 5 gpm (18.93 l/min) was set. The adjustments for water output could be viewed and controlled by the flowmeter.

Data described in the following chapters shows that the calculated average water output was, in every case, less than the value measured on a flow-through meter. The reason for this might be a relatively large constant error by the flow-through meter, or by the fact that the flow-through meter could not be read out precisely enough and, consequently, water output set more precisely. The resulting discrepancy may have been increased during the filtering operations. The water stream flowing through the filter was found to have gradually decreased, owing to the clogging of the filter; however, the operators did not continuously check it, but occasionally, only, to set water output flowing through the filter.

The filters were backwashed with raw well water at Orgovány, and with the existing water at Szeghalom, which is pre-treated using industrial scale technology. Normal practice with full scale equipment is to use treated filter effluent for backwash purposes. This practice avoids depositing suspended solids on the underside of the bed. Backwashing was required whenever the differential pressure across the filter reached a value of 10 psi, or when iron content in the treated water attained a value of 0.2 mg/l.

The resulting filtered water produced by the equipment was directed to a drain containing courtyard rainwater. Through this existing drain system there was a return flow. Backwash effluent was collected in a plastic tank of 1 m^3, washed clean, for sampling purpose. Sampling was always done after the end of backwash, following a thorough stirring of the complete backwash collected.

4.PILOT TEST RUN AT ORGOVÁNY

4.1General Description

During the experiment, well No. 1 operated at Orgovány, and the equipment purified the water drawn from this well.

The quality of influent water was somewhat different than the previously given value. The main parameters from a technological standpoint were determined again at the beginning of pilot plant, and pilot adjustments were made, taking current values into consideration. Measured values can be seen in the relating attached Tables (see Annex 1.1 and 1.2)

The mounting and installation of the equipment, as well as first days of the plant were directed and supervised by an expert of the supplying company. Following this, pilot plant tasks were performed by the local operator, independently.

The experimental pilot plant lasted from December 9th-20th, 2003. Following the mounting and operation of the equipment and also the training of the local operators, the plant was started in the morning of the second day, and the day essentially passed with adjustment and optimisation of the plant.

In the evening of the second day, the equipment first released filtered water with a quality meeting the requirements set by the manufacturer. The system was essentially installed for the next day; so, results of water quality measurements can be evaluated from this date on.

A remarkable operational problem occurred on the second day, following start-up of the pilot plant. A high effluent manganese content was found in the treated water immediately on start-up. As it turned out later, the reason for this must have been the following:

During the previous evening, following installation, the filter was backwashed. Due to the end of the workday, the standard filtering plant was not restarted, since sampling and analysis of samples would not have been possible. Therefore, starting of the filtering plant was postponed by participants to the next day, and there remained raw well water used during backwash on the filter. However, there was no chlorine in the rinsing water left on the filter, and there was a significant amount of manganese dissolved in it from the surface of the filtering matter. Correct operation was restored the same day, by standard settings of operation, and by feeding sodium hypochlorite, increased in the beginning, respectively. It is important for operation to always maintain the presence of an oxidant (chlorine) at the bottom of the media bed when in service to prevent leaching of manganese.

4.2 Main Service Run Data

4.2.1 Volume of Water

The pilot plant was operated during two complete and one part filter service runs. The main data of these service runs are as follows.

Service run #	Time of filter run date; time		Length of time	Effluent volume	Calculated average flow	
	Start	Stop	h:min	m^3	l/min	gpm
1./1	*12/10/2003 9:00*	*12/102003 10:00*	*1:00*	*0.697*	*11.62*	*3.07*
1./2	*12/10/2003 10:40*	*12/12/2003 8:29*	*45:49*	*31.334*	*11.40*	*3.01*
1.	Altogether::		46:49	32.031	11.40	3.01
2.	12/12/2003 10:05	12/17/2003 9:30	119:25	73.637	10.28	2.72
3.	12/17/2003 9:55	12/19/2003 8:00	46:05	28.334	10.25	2.71
Total:			**212:19**	**134.0**	**10.52**	**2.78**

Remark: The first filter run had two parts, because the plant was stopped once for 40 minutes, for technological adjustment.

The filter had to be backwashed twice due to high differential pressure. The main data from the backwashes are shown in the next Table.

Bw #	Time of backwash		Length of time	Waste water volume	Flow		Effluent volume	Water wastage
	date	time	min	m^3	l/min	gpm	m^3	%
1.	12/12/2003	9:42-9:55	13	0.223	17.2	4.54	32.03	0.7
2.	12/17/2003	9:30-9:50	20	0.384	19.2	5.07	73.64	0.5
Total:			**33**	**0.607**	**–**		**106**	**0.6**

The wastewater volume is about 0.5 %, which is a fairly low value. But it should also be noted that during the tests there was no rinse to waste after backwash, which would have meant a further 0.1 % water loss.

4.2.2 Chemical Feeding

Main data of solutions to be fed:

Name	Ferric chloride solution	sodium hypochlorite solution
Solution volume	15 gallon (56.8 l)	15 gallon (56.8 l)
Solution/dilution rate of concentrated chemicals	92.33 g / 15 gallon	1.558 l / 15 gallon
Agent content	0.975 g $FeCl_3$/l 0.336 gFe/l	4.12 gCl_2/l

Main data of chemical feeding:

Service Run #	Length of time	Ferric-chloride		Sodium hypochlorite	
		Average solution flow	Consumed solution volume	Average solution flow	Consumed solution volume
	h:min	l/h	l	l/h	l
2.	119:25	0.70	83.6	0.46	54.9
3.	46:05	0.70	32.3	0.43	19.8
Total:	**165:30**	**0.70**	**115.9**	**0.45**	**74.7**

Remark: In terms of chemical consumption, the first service run should not be considered, because during this time technological adjustment was in progress.

During the test run (about 212 h and 134 m^3 treated water) – owing to chemical dosing adjustment processes, too – 189 g ferric chloride hexahydrate and 2.1 l undiluted sodium hypochlorite were consumed.

Specific ferric chloride dosing values calculated from the above data are shown in the next Table:

Service run #	Length of time	Effluent volume	Calculated average flow		Ferric chloride solution dosing	Ferric chloride dosing	Specific ferric chloride dose	Iron dosing	Specific iron dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l	mg/h	mg/l
2.	119.42	73.64	10.28	617	0.70	683	1.11	235	0.381
3.	46.08	28.33	10.25	615	0.70	683	1.11	235	0.382
Total:	**165.50**	**101.97**	**10.27**	**616**	**0.70**	**683**	**1.11**	**235**	**0.382**

Specific sodium hypochlorite dosing values calculated from the above data are shown in the next Table:

Service run #	Length of time	Effluent volume	Calculated average flow		Sodium hypo-chlorite dosing	Chlorine dosing	Specific chlorine dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l
2.	119.42	73.637	10.28	617.8	0.46	1895	3.07
3.	46.08	28.334	10.25	615	0.43	1772	2.88
Total:	**165.50**	**101.97**	**10.27**	**616.2**	**0.45**	**1854**	**3.01**

4.2.3Data of Water Quality Analysis

The results of the water quality investigations can be seen in the relating Annex.

During the evaluation, the analytical results of the treated water taken during the first half of the first day of operation, (December 11, 2003) are not worth evaluating. Due to the manganese breakthrough, the technology was not operated in the desired way.

It can be said on the basis of water quality investigations that **pH** and **conductivity** of water have practically remained unchanged during water treatment. However, it is worth mentioning that the values of the conductivity measured on site have significantly and consequently differed from the values measured by the laboratory. This difference is constant and unchanged (some 30-35 μS/cm); therefore, this discrepancy can most probably be explained by the analytical-methodology employed. The measurements of OKK-OKI are similar to the results of the central laboratory; so, they must be the correct values.

Following the application of the equipment, the value of 7.37-12.5 μg/l of **arsenic content** measured in the untreated water was decreased to 2.6-8.1 μg/l. It can established from the data that efficiency of arsenic removal of the equipment is generally over 50 %, and may even reach 70-80 % (see Annex 1.3.1 and 1.3.2). Nevertheless, it may also be seen that during the filter backwashing and around the end of the filtering cycle, respectively, the efficiency of removal has decreased below 50%, parallel to an increase in the plugging of the filter. By the morning of December 17, the filter had become plugged to the point where the arsenic content rose above the influent value in the effluent water. If the filter had been backwashed sooner, and rinsed to waste following backwash, the average removal would be greater.

According to the analysis of the **arsenic forms** to be found in waters, arsenic occurred in raw waters in a proportion of 2/3 in the form of arsenite, and in a proportion of 1/3 in the form of arsenate. There can be no arsenite found in treated water, already.

In respect of **iron content,** contrary to the value of 0.30 mg/l of raw water, measured value in treated water has exceeded the valid limit value of 0.2 mg/l in the case of one sample, only. In other cases, it remained well below it; there could be 0 value measured in almost half of cases. The only extremely high value can be explained by the plugging of the filter, since it could be measured directly before the backwash of the filter. The degree of removal was 83 %.

Manganese content in raw water was 0.08-0.09 mg/l, while it generally moved between values of 0.001-0.03 mg/l in treated water. However, in the case of manganese, – as compared to iron content – it can be observed in several cases that the limit value of 0.05 mg/l was exceeded, which may be similarly explained by the plugged state of the filter. On the one hand, it is mostly characteristic of periods prior to backwash, but it can also be due to the error or inaccuracy of measurement, as well as the inaccurate adjustment of the chemical feeding – especially in the case of the extremely high values being recorded.

Following breaking point chlorination, **ammonium-ion content** of raw water could not be detected in the treated water. The **bound chlorine content** measured in the treated water strongly fluctuated between values of 0.01-1.14 mg/l, but remained well below the limit value. The reason for extreme values may be an uncertainty of measurements, but may also be a change in the quality of raw water – among others, ammonium ion content - during operation. This has been shown, for instance, by **temperature** data that changed between 14 and 20 ^{o}C, or **pH** values changing between 6.6 and 7.8. Changes were rather erratic and there can be no correlation found among them.

The value of **free chlorine content** of treated water was generally between values of 0.5-1.0 mg/l, specified by supplier of the equipment.

Total trihalomethane was not investigated, except for **chloroform** that was well below the limit value.

Treated water **can be adsorbed,** its value of **organically bound halogen (AOX)** was unfavourably high (55-64 μg/l) that has shown that - owing to chlorine feeding - the amount of secondary pollutants from organic pollutants not removed from raw water has considerably increased. (Indicative value of parameter not included in the relating orders in Germany is 25 μg/l.)

A similarly unfavourable picture has been shown by SOS index of **genotoxicity** that has reached a value of 2.3, as compared to an index value of 1.5, unanimously marking harmful biochemical activity in treated water.

4.2.4Waste Water Quality

Since following the first backwash, sludge was not removed from the collecting tank, after the second backwash, samples were taken from combined backwash waste from two cycles. So, a measurement made on the latter, gave an average result of the two backwashes.

Considering impurity content of the two samples, it can be presumed that the first sampling and subsequent measurement were not successful enough, since impurity content is generally too low, while arsenic content being too high. However, arsenic content of the second sample was some 30 % lower than expected. Owing to arsenic content, sludge and its dry solids content, respectively, are considered to be dangerous waste in Hungary.

The sludge is extremely diluted, and even the second sample has a 0,23% dry solids content, only; furthermore, a major part of dry matter content is floating matter (which might have occurred due to air coming out of the water as it warmed up). It can be seen from the sedimentation curve that pulp water is gravitationally hard to deposit; however, following sedimentation, approximately 60% of water content can be decanted. The remaining part with a 0.6% dry matter content is 2.3 thousandth of total water production. According to investigations, it can be presumed that sludge can be further concentrated and dried, if necessary.

5.PILOT TEST RUN AT SZEGHALOM

5.1General Description

The experiment was conducted in two parts at Szeghalom. The equipment was operated for one week (6-13.01.2004) with pre-treated water (treated by a water purifying equipment, existing at the local waterworks plant and disinfected by chlorine gas), and for another week (13-20.01.2004) with raw water of the well marked as II/3.

The quality of pre-treated water has somewhat differed from the previously given value. The well water treated during the second stage of experiments was tested, owing to its quality being much inferior to that of other wells. Main parameters in respect of technology were determined at the beginning of pilot plant, and plant adjustments were made, taking current values into consideration. Measured values can be seen in the attached relating Tables (see Annex 2.1, 2.2.1 and 2.2.2)

Mounting and installation of the equipment, as well as pilot plant tasks were performed by the local operator, independently.

Following mounting and installation of the equipment, as well as training of local operators, the plant was started in the afternoon, on January 6th, and the day was essentially spent by adjustment and optimisation of operation of the equipment. Adjustment was successful, and the equipment operated the same evening, already, according to requirements made by the manufacturer. The first stage of the pilot plant lasted for a week, and ended in the morning, January 13th, by stopping and backwashing, respectively.

Following the appropriate preparations, the switch to the second stage of the pilot plant lasted from morning to early afternoon on January 3rd, and the operation was evaluated in the evening. The pilot plant stage lasted until January 20th.

Comparing the two pilot plant stages, during the second stage, one filtering cycle took 5.5 less time (approx. 8 hours), owing to the quality of water to be treated, than during the first stage (approximately 45 hours). The period of backwashing was longer; consequently, there was much more sludge produced, too. Use of an air scour step in full scale equipment can reduce the time of backwash required.

An unusual problem happened during the night following the first day of pilot plant operation. The sodium hypochlorite feeding tube got blocked; therefore, chlorine feeding was insufficient. Following elimination of this problem, the plant operated regularly again.

5.2 1st Test Period (Influent Water: Pre-treated Water) – Main Service Run Data

5.2.1 Volume of Water

The pilot plant was operated during three complete and one part filter service runs. Main data of service runs are as follows.

Service run #	Time of filter run Date; time		Length of time	Effluent volume	Calculated average flow	
	Start	Stop	h:min	m^3	l/min	gpm
1./1	*01/06/2004 14:20*	*01/07/2004 8:00*	*17:40*	*11.45*	*10.80*	*2.79*
1./2	*01/07/2004 8:20*	*01/08/2004 11:47*	*27:27*	*18.68*	*11.34*	*3.00*
1.	Altogether:		45:07	30.13	11.13	2.94
2./1	*01/08/2004 12:05*	*01/09/2004 12:17*	*24:12*	*16.79*	*11.56*	*3.06*
2./2	*01/09/2004 12:25*	*01/10/2004 10:08*	*21:43*	*15.62*	*11.98*	*3.17*
2.	Altogether:		45:55	32.41	11.76	3.11
3.	01/10/2004 10:20	01/12/2004 8:00	45:40	30.14	11.00	2.91
4.	01/12/2004 8:14	01/13/2004 9:00	24:46	15.42	10.38	2.74
Total:			**161:28**	**108.1**	**11.16**	**2.95**

Remark: The first and the second filter run had two parts, because the plant had to be stopped twice, for different reasons (sodium hypochlorite dosing tube blocking, chemical solution preparation).

The filter had to be backwashed three times, altogether (ignoring backwash after the last run) because of high pressure drop. Main data of backwashes are shown in the next Table.

Bw #	Time of backwash	Length of time	Waste water volume	Flow		Effluent volume	Water wastage
	date, time	Min	m^3	l/min	gpm	m^3	%
1.	01/08/2004 11:49-12:03	14	0.246	17.57	4.64	30.13	0.8
2.	01/10/2004 10:08-10:20	12	0.234	19.50	5.15	32.41	0.7
3.	01/12/2004 8:00-8:14	14	0.250	17.86	4.72	30.14	0.8
Total:		**40**	**0.730**	**–**	**–**	**92.68**	**0.8**

Remark: The last (fourth) backwash of the first test period was required in order to start the second test period with clean filter media. Therefore, data of the last backwash are not relevant, they are not shown in the Table.

Wastewater volume is about 0.8 %, which is a fairly low value. But it should also be noted that during the tests there was no rinse to waste after the backwashing, which would have meant a further 0.2 % water loss.

5.2.2 Chemical Feeding

Main data of solutions to be fed:

Name	Ferric chloride solution	sodium hypochlorite solution
Solution volume	15 gallon (56.8 l)	15 gallon (56.8 l)
Solution/dilution rate of concentrated chemicals	92.33 g / 15 gal	0.41 l / 15 gal
Agent content	0.975 g $FeCl_3$/l 0.336 gFe/l	0.72 gCl_2/l

Main data of chemical feeding:

Service run #	Length of time	Ferric-chloride		Sodium hypochlorite	
		Average solution flow	Consumed solution volume	Average solution flow	Consumed solution volume
	h:min	l/h	l	l/h	l
1.	45:07	1.33	60.0	0.78	35.2
2.	45:55	1.34	61.4	0.99	45.6
3.	45:40	1.35	61.8	0.78	35.7
4.	24:46	1.33	32.9	0.58	14.4
Total:	**161:28**	**1.34**	**216.1**	**0.81**	**130.9**

During the test run, 351 g ferric chloride hexahydrate and 0.94 l undiluted sodium hypochlorite were consumed.

Specific ferric chloride dosing values calculated from the above data are shown in the next Table:

Service run #	Length of time	Effluent volume	Calculated average flow		Ferric chloride solution dosing	Ferric chloride dosing	Specific ferric chloride dose	Iron dosing	Specific iron dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l	mg/h	mg/l
1.	45.12	30.13	11.13	668	1.33	1297	1.94	447	0.669
2.	45.92	32.41	11.76	706	1.34	1307	1.85	450	0.637
3.	45.67	30.14	11.00	660	1.35	1316	1.99	454	0.688
4.	24.77	15.42	10.38	623	1.33	1297	2.08	447	0.718
Total:	**161.47**	**108.10**	**11.16**	**670**	**1.34**	**1307**	**1.95**	**450**	**0.672**

Specific sodium hypochlorite dosing to be calculated from the above data was the following:

Service run #	Length of time	Effluent volume	Calculated average flow		Sodium hypo-chlorite dosing	Chlorine dosing	Specific chlorine dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l
1.	45.12	30.13	11.13	668	0.78	562	0.841
2.	45.92	32.41	11.76	706	0.99	713	1.010
3.	45.67	30.14	11.00	660	0.78	562	0.852
4.	24.77	15.42	10.38	623	0.58	418	0.671
Total:	**161.47**	**108.10**	**11.16**	**670**	**0.81**	**583**	**0.870**

5.2.3Data of Water Quality Analysis

The results of the water quality investigations can be seen in the relating Annex.

It may be conclude on the basis of water quality investigations, that the **pH** and the **conductivity** of water practically remained unchanged during water treatment. Similarly, its **temperature** has changed by 3 ^oC, only, between 18 and 21 ^oC.

The value of 11-17μg/l of **arsenic content** measured in pre-treated water decreased to 6-11 μg/l. It can be concluded from the data that the efficiency of the arsenic removal of the equipment is generally below 50 %; in an average, being 37 %. (see Annex 2.3.1.1 and 2.3.1.2) Also, although the iron content in the treated water increased during filter backwashing and at the end of the filtering cycle, respectively (owing to the increase of clogging of the filter), the arsenic content and the efficiency of the arsenic removal have not definitely decreased. In fact, there have been discrepancies between local and central laboratory measurements, which might also be the reason of changing quality of water to be treated.

Arsenic forms to be found in waters were not worth investigating in the present experiment, since influent water was pre-treated and chlorinated water, and as such, arsenic would most probably be present only in the form of arsenate.

The value of 0.02-0.08 mg/l of **iron content** measured in water to be treated was generally further decreased in treated water. It has only increased nearing the end of filtering cycles, exceeding the limit value several times, since iron broke through, owing to exceeding the suspended solids holding capacity of the filter.

Manganese content in pre-treated water was 0.015-0.04 mg/l, while it has further decreased to some extent, in treated water.

There was no **ammonium ion** found in pre-treated water.

The **bound chlorine content** measured in the treated water was slightly higher, as compared to the value measured in the raw water; however, it remained between values of 0.1-0.4 mg/l. This is well below the limit value. The amount of **free active chlorine content** was primarily determined by the extent of adjusted sodium hypochlorite dosing; it was generally between values of 0.5-1.0 mg/l, specified by the supplier of the equipment.

During water treatment, the amount of trihalomethane compounds has increased, as compared to that of pre-treated water, but the value of **total trihalomethane** was below the limit value.

Pre-treated and treated water **can be adsorbed,** its **organically bound halogen** value **(AOX)** was unfavourably high (73 and 97 μg/l, respectively), which shows that owing to chlorine feeding, the amount of secondary pollutants has considerably increased from organic impurities not removed from raw water. (Indicative value of parameter not included in the relating orders in Germany is 25 μg/l.)

A similarly unfavourable picture has been shown by the SOS index of **genotoxicity** that has reached a value of 2.9, as compared to the index value of 1.5, unanimously marking harmful biochemical activity in treated water.

5.2.4Waste Water Quality

Considering the impurity content of the samples, it can be presumed that either there were inappropriate samples taken from sludge originating from the third backwash, or the subsequent measurement was unsuccessful, since impurity content was smaller than expected. Owing to arsenic content, sludge and its dry solids are considered to be hazardous waste in Hungary.

Unfortunately, the analysing laboratory has not done any investigation of sedimentation on sludge samples, but it can be presumed, on the basis of floating and dry matter content that it has similar or slightly more favourable parameters of sedimentation than the sludge from Orgovány.

5.3 2nd Test Period (Influent Water: Well Water) – Main Service Run Data

5.3.1 Volume of Water

The pilot plant was operated during fourteen filter service runs. The main data of the service runs are as follows.

Service run #	Time of filter run date; time		Length of time	Effluent volume	Calculated average flow	
	Start	Stop	h:min	m^3	l/min	gpm
1.	01/13/2004 11:40	01/13/2004 20:15	8:35	6.23	12.10	3.20
2.	01/14/2004 2:00	01/14/2004 12:00	10:00	7.30	12.17	3.21
3.	01/14/2004 15:00	01/14/2004 22:45	7:45	4.77	10.25	2.71
4.	01/15/2004 5:00	01/15/2004 13:00	8:00	5.63	11.73	3.10
5.	01/15/2004 15:00	01/15/2004 22:35	7:35	5.08	11.17	2.95
6.	01/16/2004 5:00	01/16/2004 13:00	8:00	5.37	11.19	2.96
7.	01/16/2004 14:15	01/16/2004 22:30	8:15	5.48	11.07	2.93
8.	01/17/2004 5:00	01/17/2004 15:25	10:25	6.67	10.67	2.82
9.	01/17/2004 15:45	01/17/2004 22:50	7:05	4.55	10.71	2.83
10.	01/18/2004 5:00	01/18/2004 14:00	9:00	6.63	12.28	3.24
11.	01/18/2004 14:45	01/18/2004 22:55	8:10	5.36	10.94	2.89
12.	01/19/2004 5:00	01/19/2004 13:30	8:30	5.96	11.69	3.09
13.	01/19/2004 13:50	01/19/2004 23:05	9:15	6.34	11.42	3.02
14.	01/20/2004 5:00	01/20/2004 13:20	8:20	6.32	12.64	3.34
Total:			**118:55**	**81.69**	**11.45**	**3.02**

The filter had to be backwashed thirteen times due to high pressure drop. The main data of the backwashes are shown in the next Table.

Bw #	Time of backwash	Length of time	Waste water volume	Flow		Effluent volume	Water wastage
	Date, time	min	m^3	l/min	gpm	m^3	%
1.	2004.01.13. 21:30-21:48	18	0.32	18.78	4.70	6.23	5.1
2.	2004.01.14. 12:00-12:20	20	0.40	20.00	5.28	7.30	5.5
3.	2004.01.14. 22:50-23:09	19	0.35	18.42	4.87	4.77	7.3
4.	2004.01.15. 13:05-13:22	17	0.29	17.06	4.51	5.63	5.2
5.	2004.01.15. 22:45-23:03	18	0.34	18.89	4.99	5.08	6.7
6.	2004.01.16. 13:00-13:20	20	0.31	15.50	4.10	5.37	5.8
7.	2004.01.16. 22:40-22:55	15	0.26	17.33	4.58	5.48	4.7
8.	2004.01.17. 15:30-15:45	15	0.30	20.00	5.28	6.67	4.5
9.	2004.01.17. 22:55-23:11	16	0.30	18.75	4.95	4.55	6.6
10.	2004.01.18. 14:02-14:18	16	0.30	18.75	4.95	6.63	4.5
11.	2004.01.18. 23:00-23:17	17	0.31	18.24	4.82	5.36	5.8
12.	2004.01.19. 13:35-13.50	15	0.30	20.00	5.28	5.96	5.0
13.	2004.01.19. 23:05-23:22	17	0.31	18.24	4.82	6.34	4.9
Total:		**40**	**4.09**	**–**	**–**	**75.37**	**5.4**

Wastewater volume is about 5.4 %, being a fairly low value. But it should also be noted that during the tests there was no rinses to waste after backwash, which would have meant a further water loss of 1.1 %.

5.3.2Chemical Feeding

Main data of solutions to be fed:

Name	ferric chloride solution	sodium hypochlorite solution
Solution volume	15 gallon (56.8 l)	15 gallon (56.8 l)
Solution/dilution rate of concentrated chemicals	857.4 g / 15 gal	1.114 l / 15 gal
Agent content	9.046 g $FeCl_3$/l 3.110 g Fe/l	1.96 g Cl_2/l

Main data of chemical feeding:

Service run #	Length of time	Ferric-chloride		Sodium hypochlorite	
		Average solution flow	Consumed solution volume	Average solution flow	Consumed solution volume
	h:min	l/h	l	l/h	l
1.	8:35	1.37	11.7	1.79	15.3
2.	10:00	1.40	14.0	2.21	22.1
3.	7:45	1.34	10.4	1.86	14.4
4.	8:00	1.41	11.3	1.75	14.0
5.	7:35	1.31	9.92	1.61	12.2
6.	8:00	1.35	10.8	1.86	14.9
7.	8:15	1.31	10.8	1.81	14.9
8.	10:25	1.39	14.4	1.91	19.9
9.	7:05	1.15	8.12	1.66	11.7
10.	9:00	1.37	12.4	1.83	16.4
11.	8:10	1.30	10.7	1.80	14.7
12.	8:30	1.39	11.8	1.88	16.1
13.	9:15	1.45	13.5	2.15	19.9
14.	8:20	1.32	11.0	1.82	15.2
Total:	**118:55**	**1.35**	**160.8**	**1.86**	**221.6**

During the test run, 2430 g ferric chloride hexahydrate and 4.4 l undiluted sodium hypochlorite were consumed.

Specific ferric chloride dosing values calculated from the above data are shown in the next Table:

Service run #	Length of time	Effluent volume	Calculated average flow		Ferric chloride solution dosing	Ferric chloride dosing	Specific ferric chloride dose	Iron dosing	Specific iron dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l	mg/h	mg/l
1.	8.58	6.23	12.10	726	1.37	12393	17.1	4261	5.87
2.	10.00	7.30	12.17	730	1.40	12664	17.3	4354	5.96
3.	7.75	4.77	10.25	615	1.34	12122	19.7	4167	6.77
4.	8.00	5.63	11.73	704	1.41	12755	18.1	4385	6.23
5.	7.58	5.08	11.17	670	1.31	11850	17.7	4074	6.08
6.	8.00	5.37	11.19	671	1.35	12212	18.2	4199	6.25
7.	8.25	5.48	11.07	664	1.31	11850	17.8	4074	6.13
8.	10.42	6.67	10.67	640	1.39	12574	19.6	4323	6.75
9.	7.08	4.55	10.71	643	1.15	10403	16.2	3577	5.57
10.	9.00	6.63	12.28	737	1.37	12393	16.8	4261	5.78
11.	8.17	5.36	10.94	656	1.30	11760	17.9	4043	6.16
12.	8.50	5.96	11.69	701	1.39	12574	17.9	4323	6.17
13.	9.25	6.34	11.42	685	1.45	13117	19.1	4510	6.58

14.	8.33	6.32	12.64	759	1.32	11941	15.7	4105	5.41
Total:	**118.92**	**81.69**	**11.45**	**687**	**1.35**	**12212**	**17.8**	**4199**	**6.11**

Specific sodium hypochlorite dosing values calculated from the above data are shown in the next Table:

Service run #	Length of time	Effluent volume	Calculated average flow		Sodium hypo-chlorite dosing	Chlorine dosing	Specific chlorine dose
	h	m^3	l/min	l/h	l/h	mg/h	mg/l
1.	8.58	6.23	12.10	726	1.79	1962	2.70
2.	10.00	7.30	12.17	730	2.21	2422	3.32
3.	7.75	4.77	10.25	615	1.86	2039	3.31
4.	8.00	5.63	11.73	704	1.75	1918	2.73
5.	7.58	5.08	11.17	670	1.61	1765	2.63
6.	8.00	5.37	11.19	671	1.86	2039	3.04
7.	8.25	5.48	11.07	664	1.81	1984	2.99
8.	10.42	6.67	10.67	640	1.91	2093	3.27
9.	7.08	4.55	10.71	643	1.66	1819	2.83
10.	9.00	6.63	12.28	737	1.83	2006	2.72
11.	8.17	5.36	10.94	656	1.80	1973	3.01
12.	8.50	5.96	11.69	701	1.88	2060	2.94
13.	9.25	6.34	11.42	685	2.15	2356	3.44
14.	8.33	6.32	12.64	759	1.82	1995	2.63
Total:	**118.92**	**81.69**	**11.45**	**687**	**1.86**	**2039**	**2.97**

5.3.3Data of Water Quality Analysis

Results of water quality investigations can be found in the relating Annex.

It can be seen on the basis of water quality investigations that **temperature** and **conductivity** of water have practically remained unchanged during water treatment, while **pH** has decreased to a small extent.

The value of 105-135 µg/l of **arsenic content** measured in untreated water has decreased to 22-38 µg/l, which exceeds the limit value of 10 µg/l. It can be seen from data that efficiency of arsenic removal of the equipment may exceed 75 %, and even 80 %, in an average; however, this has been insufficient for the decrease of arsenic content below the limit value (see Annex 2.3.2.1 and 2.3.2.2)

> It is feasible that arsenic content can be even more decreased by further optimisation of chemical feeding (e.g. by the increase of ferric chloride dosing); however, this would mean an even more rapid plugging of the filter, its more frequent backwash and specifically, more sludge formed. Another possibility would to feed acid to lower the pH of the feed water to 7.3, a value found in other studies to be more favorable to co-precpitation of arsenic on ferric hydroxide.

According to the investigation of **arsenic forms** to be found in waters, approximately 90% of arsenic content in raw water has been arsenite. There can be no arsenite found in treated water, already.

The value of 0.07-0.14 mg/l of **iron content** measured in water to be treated has further decreased in treated water, as a general rule. It increased nearing the end of filtering cycles, only; exceeding the limit value several times, since iron broke through, owing to plugging of the filter. Stopping the filter service cycle sooner can avoid this problem.

Manganese content in pre-treated water was 0.015-0.04 mg/l, and slightly continued to decrease in treated water.

As a result of break point chlorination, the **ammonium ion content** of the raw water could not be detected in the treated water. The **bound chlorine content** measured in the treated water fluctuated between the values of 0.1-1.2 mg/l, but remained well below the limit value to the end. The reason for fluctuation must have been the change of chlorine feeding and, eventually, a change occurred in the quality of raw water (e.g. ammonium ion content). The value of **free chlorine content** of treated water was generally between the value of 0.5-1.0 mg/l, specified by supplier of the equipment.

Total trihalomethane, as well as values of **organically bound halogen (AOX) to be adsorbed** and **genotoxicity** were not investigated.

5.3.4Waste Water Quality

During backwashing, required by the operation, there were three samples taken of the sludge. From among these three samples, the second one does not fit into the row. Considering its impurity content, it can be presumed that either there was a sample taken or the subsequent measurement was unsuccessful, since impurity content was much higher than expected. Owing to arsenic content, pulp water and its dry matter content are considered to be hazardous waste in Hungary.

Unfortunately, the examining laboratory has not made an investigation of sedimentation on sludge samples; however, it can be presumed on the basis of floating- and dry matter content, that it has similar or slightly more favourable parameters of sedimentation than the sludge from Orgovány.

6.SUMMING EVALUATION OF PILOT PLANT TESTS

Thus far, the technology has been very similar to the ones generally applied in Hungary. Its treatment is usual, simple, automatizable, monitorable and does not require any special professional knowledge. Nevertheless, its operation demands caution and careful work, in order to ensure that the impurity concentration of the treated water does not exceed the limit value, with respect to individual parameters, backwash should be made in due time and chemical feeding should be proportional with the yield of effluent water and appropriate to its quality.

The chemicals to be fed are used in Hungary and have a licensed application. Their treatment can be solved with strict observance of the relating prescriptions of safety and labour protection.

Sodium hypochlorite, used during the experiments, can be replaced by chlorine gas or potassium permanganate, too; as a function of quality of the given raw water and quality to be achieved of treated water, respectively. Anyway, a free active chlorine level higher than 0.3-

0.5 mg/l in treated water has been undesirable in Hungary; primarily because chlorine deteriorates organoleptic properties of water.

During pilot plant experiments, this technology could remove arsenic to an appropriate extent from low arsenic content waters (10-30 μg/l), and arsenic content in treated water was below the limit value. Nevertheless, the extent of removal has proven to be insufficient in the case of the high arsenic content well water of Szeghalom.

The technology has been suitable for operations of both basic and high technology. In general, the lifetime of the filtering matter is expected to be as much as that of filtering pebbles integrated with manganese dioxide.

The technology has no harmful effect whatsoever on the environment; pulp water and sludge, harmful to the environment must be collected and - if possible - dehydrated, prior to its definitive placement (e.g. at a hazardous waste storing plant).