A BRIEF TECHNICAL AND ECONOMICAL SURVEY OF THE

ON-SITE CHLORINE PRODUCTION

FROM A KITCHEN SALT SOLUTION UNDER INDONESIAN CONDITIONS.

International Water Supply Consultants
IWACO B.V.
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SUMMARY.

A technical/economic survey was made to obtain an insight into the possibilities of the on-site production of an active chlorine solution for disinfection at a treatment plant with a capacity of 1440 m^3/h (400 l/s).

The survey showed the on-site production of chlorine to be an attractive process under Indonesian conditions considering the economic and safety aspects.
However, little experience with this rather sophisticated technology for drinking water disinfection is available yet.

It is therefore recommended to test this new technology on a small scale to see if it is a feasible alternative for conventional chlorination.

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ANNEX V Process scheme and process operation.

1. INTRODUCTION.

An important group of pollutants in water which are injurious to health are the micro-organisms. A water treatment process has to remove the micro-organisms (disinfection process). Most commonly, disinfection is obtained by chlorine or chlorine compounds.

A conventional disinfection system, using chlorine, consists of the storage of chlorine gas in containers, dosing devices, alarms and controls.

At the moment, systems are available which avoid the transport and storage of the highly aggressive and dangerous chlorine gas: the on-site production of active chlorine from saline waters such as sea water or a kitchen salt solution. The active chlorine is generated by electric decomposition of the sodium chloride; at the anode chlorine gas is evolved, and at the cathode hydrogen gas and sodiumhydroxide are generated.

Two different types of electrolysis cells are available, the "one chamber type" cells, in which the anodes and cathodes are placed in the same electrolysing chamber, and the two chamber cells, in which the anodes and cathodes chambers are separated by membranes. In the one chamber cells the electrolysis products can react instantaneously, thus forming a hypochlorite solution. In the two chamber cells electrolysis products are separately evacuated from the cell.

It is generally stated that the efficiency of the two chamber elctrolysis cells will be higher than the efficiency of the one chamber cells; however, the technology of the two chamber cells is rather complicated, resulting in high investments and maintenance costs.
The one chamber cells are far more simple and easy to maintain and control. For this reason the "one chamber" cell systems can be considered more appropriate for Indonesian circumstances than the "two chamber" cell systems.

When the on-site production of active chlorine from saline waters with one chamber type cells is considered more in detail, the electrolysis of a kitchen salt solution is more interesting to use for drinking water disinfection than the electrolysis of seawater. Kitchen salt (sodiumchloride) is widely commercially available and all equipment is concentrated at the waterworks site. The on-site production of active chlorine from seawater requires a rather sophisticated seawater treatment plant, consisting of chemical coagulation, flotation and filtration, which is complicated to operate and which requires skilled personnel. Moreover, a seawater intake station, a pumping station and a transport main are needed.

For disinfection at a surface water treatment plant a preliminary technical/economic survey is presented here to provide an insight into the possibilities of the on-site production of active chlorine from a kitchen salt solution.

In order to obtain a realistic comparison the study was based on the proposed New Water Treatment Works in Balikpapan, Kalimantan, which will have a capacity of 400 l/s (1440 m3/h).

The survey was performed by the staff of IWACO International Water Supply Consultants B.V. (Rotterdam, The Netherlands) and Dr. Ir. A. Gerritsen of the Technical University of Bandung (ITB), Indonesia.

ASSUMPTIONS.

The survey is based on the following assumptions:

a. Flow.
Assumed nominal flow to be treated: 400 L/s.

b. Dosage.
Chlorine dosage for disinfection: 4 gram/m3.
Thus the nominal quantity of chlorine daily required is 140 kg/day.

c. Costfactors (prices January 1979, Balikpapan conditions).

- costs of electricity supplied by PLN	Rp 25/kWh
- fuel costs of electricity generated on site	Rp 10/kWh
- costs of sodiumchloride (kitchen salt)	Rp 40/kg
- costs of chlorine gas, delivered in pressurised containers on the site	Rp 650/kg

d. Capital costs (January 1979).

- PLN (electricity board) connection	Rp 150,000/kW
- Generating equipment (diesel engine and associated equipment, excluding L.V. switch gear and cables).	Rp 450,000/kW

e. Maintenance.

- Maintenance of technical equipment:
  4% of capital costs per year.
- Maintenance of PLN (electricity board) connection: 2% of capital costs per year.
- Maintenance of generating equipment:
  7% of capital costs per year.

f. Rate of conversion (January 1979).

Dfl 1,-- = Rp 310,--

US$ 1.-- = Rp 620,--

g. Spare parts.

Spare parts are included in the equipment capital costs (5%).

h. Civil work.

The costs of civil works for on-site chlorine production and conventional chlorine gas systems are in the same range and have only a minor effect on the cost-evaluation. They are therefore not included in the economic calculations.

ad e) The life-time of the electrodes is about 15-20 years. However, the coating (titanium) of the electrodes has to be renewed every 2 years. The costs for recoating the electrodes are considered to be 2% per year of the capital costs of the electrolysing unit. The maintenance costs of the electrolysing unit are estimated at 2% of the investment costs.

3. ECONOMIC ASPECTS.

The preliminary survey shows the following economic results (table 1) (see Annex III).

Table 1: Capital and Operating costs in million Rp.

System	Capital costs	Present value of accumulated operation costs during economic life time	Total present value
A. Chlorine gas delivered in pressurised containers	60	229	289
B. On-site chlorine production from kitchen salt. Equipment adjusted to European conditions and cost factors (Seaclor system)			
B.1. Electricity PLN	72	133	205
B.2. Electricity generated from diesel fuel.	81	108	189
C. On-site chlorine production from kitchen salt. Equipment, economically adjusted to Indonesian costs factors.			
C.1. Electricity PLN	73	116	189
C.2. Electricity generated from diesel fuel	84	87	171

From Table 1 it is clear that the investment costs of the on-site production of chlorine from a kitchen salt solution are 18% to 40% higher than the investment costs of the chlorine gas system. The total present value however is lowest for the on-site chlorine production. A decrease in the total present value of 29 - 40% can be obtained when the on-site production of chlorine is used.

Presumably, the technical process conditions of the on-site chlorine production can be further optimized to the Indonesian circumstances resulting in even lower yearly operating costs.

Not included in the economic survey are the investment costs for stand-by disinfectant equipment which is usually provided for the chlorine gas system. When the on-site chlorine production is applied for disinfection, no dissolving and dosing equipment has to be installed contrary to the chlorine gas system.

4. TECHNICAL ASPECTS.

Apart from the economic aspects, the following technical aspects can be noted.

- Gaseous chlorine.

  The conventional chlorine system requires transport and storage of the dangerous gas. However, the operations for dosage and maintenance are not too complicated and well known.

- On-site production of active chlorine from a kitchen salt solution.

  For the on-site production of chlorine from a kitchen salt solution, transport and storage of the sodium chloride salt is necessary. Humidity may cause problems during dry storage of the salt. With "wet" storage this problem is avoided. Only little experience is available in the field of drinking water treatment yet.

5. SAFETY ASPECTS.

When taking into account the safety aspects, the on-site production is to be preferred to the conventional system because the transport, storage and handling of the dangerous chlorine gas can be avoided.

6. PURCHASE OF CHEMICALS.

Arrangements for the supply of kitchen salt will be more easy than for gaseous chlorine. In emergency cases kitchen salt can even be bought on the local market, while for gaseous chlorine only a few distant manufacturers exist. For this reason a considerable stock of gaseous chlorine has to be kept on the treatment works normally. In addition, hypochlorite stand-by equipment is often installed to cover the risk of late supply of chlorine containers.

7. EVALUATION OF THE SYSTEMS.

The final decision as to which disinfectant system would be chosen will depend on the advantages and disadvantages of the systems involved. The various aspects are enumerated in Table 2.

Table 2: Comparison of various aspects of the two disinfectant systems.

Aspects	Chlorine gas delivered on the site in pressurised containers	Chlorine produced on the site from kitchen salt
Total present value (million Rp)	289	171 - 205 depending on cost factors
Technical level of the disinfectant systems	Sophisticated but well known	Sophisticated but limited experience
Additional Equipment	- Storage of chlorine gas containers - Stand-by equipment for hypochlorite required	- Storage and dosing of sodiumchloride - Storage of active chlorine solution (p.m).
Special Requirements	- Alarmsystems - Gas-Evacùation systems - Safety equipment	Hydrogen release valves

Table 2: Enumeration of various aspects of the two disinfectant systems (cont'd).

Aspects	Chlorine gas delivered on the site in pressurised containers	Chlorine produced on the site from kitchen salt
Problems during operations	- corrosion problems - continuous supply from distant manufacturers	- Humidity control in salt storage reservoir. - Cleaning of electrodes
Safety	Transport and storage of chlorine	Prevention of hydrogen-oxygen explosive mixtures
Experience	Widely used	Very little experience with drinking water disinfection plant available

8. CONCLUSIONS.

In the preceding chapters a technological/economic survey of the 2 chlorine systems involved, compared the various aspects such as costs, technology, safety, feasibility, etc. The survey is based on the prevailing conditions in Balikpapan.

The on-site production of an active chlorine solution from a kitchen salt solution showed to be economically more interesting than the conventional chlorine system with respect to total present value during economic life. A saving of 29-40% of the total present value can be obtained. The optimization of process conditions on the local cost factors is less important. However, when the technical conditions can be optimized to local circumstances the system of on-site chlorine production might be economically even more interesting. The economic advantage of the on-site system would disappear if the price of chlorine gas supplied in containers was to fall below Rp 400/kg (now Rp 650/kg). This might well be possible since the present price seems unreasonably high. The technology of the conventional system is widely known in contrast to the on-site system, which is seldom used for drinking water purposes: there is still a lack of sufficient experience with this on-site system.

Considering the safety aspects of both systems, the on-site system should be preferred to the conventional system.

Furthermore, the problem of ensuring a continuous supply of chlorine gas would be simplified in case of on-site production from kitchen salt.

In our opinion, on-site production of chlorine from a synthetic brine is interesting as a method to eliminate the use of liquid chlorine with its associated problems. It would be desirable to test this technology, in first instance on a small scale, to see whether it is an adequate alternative for conventional chlorination.

ANNEX I

A disinfection plant with chlorine gas.

A disinfection plant based upon delivery on the site of chlorine gas in pressurised containers consists of:

- handling facilities for loading, unloading and transport of containers;
- stock of containers;
- weighing scales;
- automatic scales;
- chlorinators;
- dosage equipment;
- chlorine gas control, alarms and evacuation or neutralising systems;
- personal safety equipment;
- stand-by equipment for hypochlorite (HTH) dosing will usually be required to cover the risk of a discontinuity in supply of chlorine gas.

ANNEX II

Background information concerning on-site production of active chlorine.

1. THE CHEMICAL PROCESS.

On-site production of active chlorine is effected by partial electrolytic decomposition of sodiumchloride (kitchen salt, NaCl) solution or of seawater.
The sodiumchloride solution flows between the anodes and cathodes of an electric cell. Chlorine is evolved at the anode, sodium hydroxyde and hydrogen are generated at the cathode. The chlorine and sodium hydroxyde mix and react to form sodium hypochlorite. The chemical reaction can be written as:

Electrolysis

Anode	$2\,Cl^- = Cl_2 + 2e$	(1a)
Cathode	$2\,Na^+ + 2\,H_2O + 2e = 2\,NaOH + H_2$	(1b)
Overall	$2\,NaCl + 2H_2O = Cl_2 + 2NaOH + H2$	(1)

Solution

$$Cl_2 + H_2O = HOCl + HCl \quad (2a)$$

$$2\,NaOH + HOCl + HCl = NaOCl + 2\,H_2O + NaCl \quad (2b)$$

$$Cl_2 + 2\,NaOH = NaOCl + H_2O + NaCl \quad (2)$$

Overall reaction electrolysis and solution reaction:

$$2\,NaCl + H_2O = NaOCl + NaCl + H_2$$

Next to the main reaction several side reactions can occur (see figure 1).

1) Anodic discharge of OCl^- ions

$$6\ OCl^- + 6\ OH^- = 2\ ClO_3^- + 4\ Cl^- + 3/2\ O_2 + 3H_2O + 6e$$

b) Anodic discharge of OH^- ions

$$2\ OH^- = H_2O + 1/2\ O_2 + 2e$$

c) Cathodic reductions of OCl^- ions

$$OCl^- + 2H^+ + 2e = Cl^- + H_2O$$

d) Loss of generated hypochlorite in situ by the reaction with readily oxidizable substances in the water such as Fe^{2+}, NH_4^+ and organic matter.

The strength of chlorine solution produced is expressed as available chlorine or equivalent chlorine.
By definition the equivalent chlorine is that quantity of chlorine having the same oxidizing effect as hypochlorite when analysed by standard methods.

2. Water quality for and chlorine generated at on-site production of chlorine.

On-site production of active chlorine can be obtained from any solution with a salinity of 10-40 gram/l. Two sources of saline water can be used:

- seawater;
- a kitchen salt solution (synthetic brine).

The water must be free of suspended solids, free of suspended organic materials and free of oil substances. Substances which can cause scaling should be absent. The water must be disinfected in advance.

The effluent of the electrolysing unit will contain about 1 - 5 gram chlorine per liter.

3. Energy Consumption.

The electrolysing process requires energy. An average of 4-5 kWh is required to produce one kg chlorine. The energy consumption depends on temperature, salinity, AC/DC conversion and rated load.

4. Cleaning of Electrodes.

The electrodes have to be cleaned once a month with hydrochloric acid to remove scaled compounds. For cleaning, about 0.5 kg HCl is required per 1000 kg active chlorine produced.

Water Qualit; Changes.

Due to the required salinity of the electrolysing solution, the sodium and chloride contents of the drinking water will increase. Calculations show an increase of about 20 gram/m^3 chloride.

Storage.

The chlorine solution, obtained with the electrolysing process can be stored 2-3 days only; due to a relatively high temperature and the sun light an activity deterioration takes place.

General equipment for the electrolysing process.

The system consists of the following basic units:

- electrical conversion unit (AC/DC-unit);
- equipment for make-up of kitchen salt solution;
- electric cells;
- storage and recycling tank(s);
- control and alarm systems hydrogen release valves, switch gear;
- dosing equipment;
- pumps.

Spare parts.

The lifetime of the electrodes is rather long (15 years). However, at least some spare electrodes have to be available.

Electrodes

The titanium coating of the electrodes has to be renewed every two years.

ANNEX III

Cost calculations.

A. **Chlorine gas delivered on the site in pressurised containers.**

A. Capital costs	
- stock of containers, chlorinators, dosage equipment, automatic switch overs, weighing scales, chlorine gas control, alarms and evacuations system.	Rp 60.0 x 106
	===============
B. Yearly operating costs	
- chlorine gas: 140 kg/day	Rp 33.2 * 106
- maintenance:4% of investments	Rp 2.4 * 106
Yearly operating costs	Rp 35.6 * 106
	===============

* Present value of accumulated operating costs (10 years: 9%) Rp 229 * 106.

** Capital + present value operating costs Rp 289 x 106.

1 **On-site chlorine production (140 kg/day) from a kitchen salt solution (25°C).**

A. Capital costs.

- Storage of kitchen salt (100 tons), dissolving tank (3 m^3), chlorine storage tank (12 m3) dosing pumps, pumps and auxialliary equipment, electrolysing unit, including spare parts	Rp 68 x 10^6
- PLN (electricity board) connection (excl. L.V. switchgear and cables) (30 kW)	Rp 3.5 x 10^6
Capital costs	Rp 71.5 x 10^6

B. Yearly operating costs.

- sodiumchloride 5 kg NaCl/kg chlorine	Rp 10.2 x 10^6
- electricity 6 kWh/kg chlorine	Rp 7.7 x 10^6
- maintenance chlorine production systems (4%)	Rp 2.7 x 10^6
- maintenance PLN connection(2%)	Rp 0.1 x 10^6
Yearly operating costs	Rp 20.7 x 10^6

* Present value of accumulated operating costs (10 years; 9%) Rp 133 * 10^6

** Capital + present value operating costs Rp 204.5 * 10^6

B.2 <u>On-site chlorine production (140 kg/day) from a kitchen salt solution using electricity generated from diesel fuel (on-site).</u>

A. Capital costs.

- Storage of kitchen salt, dissolving tanks, chlorine storage tanks, dosing pumps auxilliary equipment, electrolysing unit, including spare parts	Rp 68 x 106
- Generating equipment (30 kW) (excluding L.V. switchgear and cables)	Rp 13.1 x 10^6
Capital costs	Rp 81.1 x 106

B. Yearly operating costs.

- Kitchen salt 5 kg NaCl/kg chlorine	Rp 10.2 x 106
- electricity 6 kWh/kg chlorine	Rp 3.0 x 106
- maintenance chlorine production system (4%)	Rp 2.7 x 106
- maintenance generating equipment (7%)	Rp 0.9 x 10^6
Yearly operating costs	Rp 16.8 x 106

* Present value of accumulated operating costs (10 years; 9%) Rp 108 * 106

** Capital + present value operating costs Rp 189 * 106

1 <u>On-site chlorine production (140 kg/day) from a kitchen salt solution (25%) (optimized conditions electricity PLN).</u>

A. Capital costs.

- Storage of kitchen salt etc. electrolysing unit, including spare parts	Rp 68 x 106
- PLN connection (38 kW)	Rp 4.5 x 10^6
Capital costs	Rp 72.5 x 106
	===============

B. Yearly operating costs.

- Sodium chloride 3,5 kg/kg chlorine	Rp 7.1 x 106
- *electricity 6,4 kwh/kg chlorine*	*Rp 8.2 x 106*
- maintenance (4%) electrolysing unit	Rp 2.7 x 106
- maintenance (2%) PLN connection	Rp 0.1 x 10^6
Yearly operating costs	Rp 18.1 x 106
	===============

* Present value of accumulated operating costs (10 years; 9%) Rp 116 * 106

** Present value of accumulated operating costs + Capital = Rp 189 x 106

Ad B. It is assumed that when operating under the process conditions as mentioned in this item, an electrolysing unit can be used equal in dimensions to the unit used for European conditions.

C.2 **On-site chlorine production (140 kg/day) from a kitchen salt solution using energy generated from diesel fuel (optimized).**

A. Capital costs.

- Storage of kitchen salt etc. electrolysing unit, including spare parts	Rp 68 x 106
- Generating equipment (35 kW)	Rp 15.9 x 10^6
Capital costs	Rp 83.9 x 106

B. Yearly operating costs.

- Chemicals 3,3 kg NaCl/kg chlorine	Rp 6.7 x 106
- electricity 5,9 kwh/kg chlorine	Rp 3.0 x 106
- maintenance (4%) electrolysing unit	Rp 2.7 x 106
- maintenance (7%) generating equipment	Rp 1.1 x 10^6
Yearly operating costs	Rp 13.5 x 106

* Present value of accumulated operating costs (10 years; 9%) Rp 87 x 106

** Capital costs + present value operating costs. Rp 171 x 106

Ad B. It is assumed that when opeating under the process conditions as mentioned in this item, an electrolysing unit can be used equal in dimension to the unit used for the European conditions.

ANNEX IV

Calculation of the "break-even price" of chlorine gas.

The break-even price of chlorine gas is that price of chlorine gas that will result in the same total costs (capital costs and present value of accumulated operating costs during the economic life (10 years at 9% capital costs) for disinfection as the on-site chlorine production process.

The total costs of on-site production of chlorine amount to Rp 205 million in the most infavorable case (BI). As capital costs and accumulated maintenance costs of case A (chlorine gas delivered in pressurized containers) amount to Rp 84 million, it follows that for a break-even point, the difference ad Rp 145 million should equalize the present value of the accumulated costs of chlorine gas. On a yearly basis, therefore, costs of chlorine gas should amount to Rp 20.3 million or Rp 397 per kg.

When the price of chlorine gas, based on the prices of january 1979 will drop with 37%, both disinfectant systems will yield equal total costs.

ANNEX V

Process-scheme and process-operation.

a. Flowsheet.

The flow-sheet of the on-site active chlorine production plants comprises the following units:

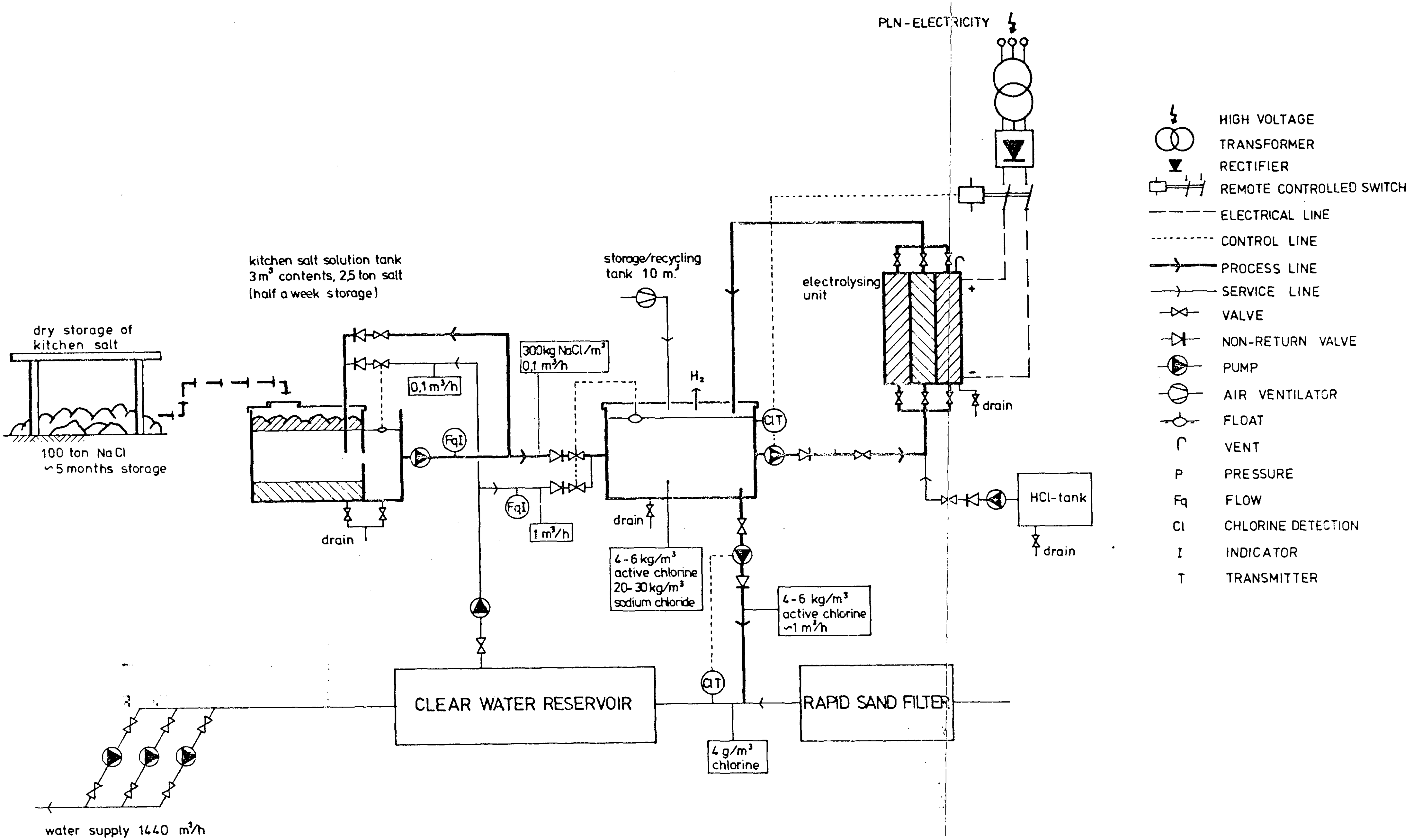
- salt storage building (100 Ton NaCl);
- salt "wet" storage and dissolving pit, complete with strainers, dosing pump, valves, non return valves and waterlevel controls;
- active chlorine storage and recycling tank (10 m3) complete with drains, level controls, chlorine detector, transmitter, pumps and air purging tan;
- active chlorine dosing pump;
- hydrochloric acid storage tank and pump;
- electrolysing unit for an active chlorine production rate of 8 kg/h. complete with piping and auxilliary equipment;
- electrical conversion unit;
- set of DC connection from rectifyer to the electrolysing unit.

b. Process-operation.

Active chlorine, produced in the electrolysing cells is stored in the storage and recycling tank. From this tank active chlorine is dosed in the clear water reservoir. When the level in the storage and recycling tank due to the dosing has reached a certain low level, a diluted salt solution is fed to the storage and recycling tank while at the same time the electrolysing units are set in operation.

The inflow of the diluted salt solution is ceased when a certain high level in the storage and recycling tank has been reached.

The electrolysing process continues till a certain active chlorine concentration is reached. The diluted salt concentration is obtained by mixing service water with a concentrated salt solution from the salt saturator.



PROCESS SCHEME ON-SITE PRODUCTION OF ACTIVE CHLORINE FOR DISINFECTION
AT A WATER TREATMENT PLANT WITH A CAPACITY OF 1440 m³/h

ADVIESBUREAU VOOR WATERVOORZIENING IWACO B.V. INTERNATIONAL WATER SUPPLY CONSULTANTS	PROJEKT ON-SITE CHLORINE PRODUCTION		RAPPORT NR
	GET	GEZ	DAT april 1979	FIGUUR NR
	OPDRACHTGEVER		
SCHIEKADE 189 ROTTERDAM TEL 010-14 37 78			