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El-Salaam Canal Water, Sinai, Egypt. Part V. Techno-economic study for integrated treatment plant

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ABSTRACT

The water quality of El-Salaam canal, in Sinai, Egypt is chemically and biologically polluted because it is a mixture of Nile water and Drainage water. Complex treatment plant is proposed which consists of three types of plants: primary water filtration and chlorination (PWFC) treatment plant of 20,000 m^3/day capacity, ultrafiltration (UF) water treatment plant of 2400 m^3/day capacity and brackish water reverse osmosis (BWRO) treatment plant of 2400 m^3/day capacity. The aim of this article is to present design considerations, system components, process description and material balance calculations of each plant. Based on the presented techno-economic study, the fixed capital cost of the PWFC, the UF and BWRO are 2,502,000, 2,815,460 and 3,216,000 L.E., respectively, the annual operating costs are 115,500, 443,660 and 1,829,620 L.E., while the cost of one cubic meter treated water is 0.4, 3.7 and 7.38 L.E. for the PWFC, the UF and BWRO, respectively (1U$ dollar = 5.5 L.E.).

Keywords: Design; Physiochemical treatment; Ultrafiltration; Reverse osmosis; Economic

1. Introduction

The Egyptian Academy of Scientific Research and Technology (ASRT) funded research project entitled ''Treatment of Nile water in Sinai'' which implemented by a team work from national research centre (NRC), Egypt [1]. The project aims to carry out field survey on El-Salaam canal waters which is a mixture of Nile water and drainage water to recognize their quality and what it bear of possible dangers. Furthermore, propose measures for control and/or remediation of these hazards, using traditional and modern techniques for treatment of canal waters. Tailored monitoring program to study the water quality of El-Salaam Canal chemically and biologically at seven locations monthly for 12 months was carried out by the NRC team [2]. The chemical analysis indicated that the maximum total dissolved solid (TDS) is 2060 mg/L which is double the designed value of El-Salaam Canal (1000:1200 mg/L). In addition the canal water is characterized by high content of unacceptable and harmful level of heavy metals and dissolved organic matters. Biologically, the raw water is characterized by the existence of total coli form and pathogenic bacteria. The study proved that the Canal water is chemically and biologically not suitable for irrigation or for drinking purposes for animal and human and need treatment. Bench and pilot scale treatment experiments were carried out by the NRC team to treat water to be used for the different purposes [3,4]. The treatment and separation methods used were physiochemical treatment and membrane separations technologies including ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The main objective of this article is to present the

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proposed complex treatment plant to produce water of different quality for different uses in the new communities (5000 population capacity for each community) which recommended to be established in Sinai around El-Salam canal water based on experimental treatment. Also an economic study for the complex treatment unit will be included in this article.

2. Process design of complex treatment plant

The complex treatment plant consists of three types of plants: primary water filtration and chlorination (PWFC) treatment plant, UF water treatment plant and brackish water reverse osmosis (BWRO) treatment plant.

2.1. PWFC treatment plant

The capacity of the PWFC treatment plant is 20,000 m^3/day. The productive water resulted from the PWFC treatment plant is brackish water which is disinfected by chlorination before uses. Seventy five percent of the resulted treated water will be used to irrigate trees except trees of fruits and plants such as corn and rice which will be cooked before eating. The 25% of water rest is used as influent for the UF and SWRO treatment plants.

2.1.1. The Design Considerations

The design considerations are:

(a) The plant capacity is of 20,000 m^3/day.
(b) The characteristics of inlet water (maximum value) are presented in Table 1.
(c) The results of bench and pilot scale experiments of filtration and chlorination which proved that the filtration will remove 15% of suspended solids (SS), 11% of CDD and 7% of total organic matters (TOC) as average values and the chlorination will remove all types of *Escherichia coli* and pathogenic bacteria.

2.1.2. Plant components

The plant components are: inlet, screen, pumping station, pumps for pumping water, chlorination building, chlorine dosing pump, sand filters, pumps for back wash, control board for back wash pumps, electricity station, storage tank, measurement and control system and piping system.

2.1.3. Process description

The suggested operating system consists of: screening, primary chlorination, primary sand filtration, final chlorination and pumping station. The raw water will flow through pipe line equipped with screen to remove high particle sizes, and then water is chlorinated and pumped to 8 rapid sand filter basins. The out let water will pass to pumping station to be pumped to three directions after finally chlorinated. The first direction to be used in irrigation and the second direction to UF plant and the third one to BWRO plant. The sand filter is usually back wash for 30 min/day. Fig. 1 represents the equipment flow diagram of pre-treatment plant.

2.1.4. Material balance

The plant material balance calculations are shown in Fig. 2 based on 1 h.

2.2. UF water treatment plant

The inlet water flow is the water resulted from PWFC treatment plant. The capacity of the UF treatment plant is 2400 m^3/day. The productive water resulted from the UF treatment plant is brackish water which uses in irrigation of eatable fruits and vegetables, decorated plants and medical plants.

2.2.1. Design considerations

The design considerations are:

(a) The plant capacity is 2400 m^3/day.
(b) The characteristics of inlet water are the characteristics of water resulted from the PWFC treatment plant as presented in Table 1.
(c) Results of bench and pilot scale experiments, where 2.5 mg/L of nonionic polymer is used as coagulant in the coagulation, flocculation process. The polymer succeeded to remove SS, chemical oxygen demand (COD) and TOC by 91%, 63.5% and 81%, respectively.

2.2.2. Plant components

The plant components are: pumping station, coagulation/flocculation and settling unit, Chlorination building, chlorine dosing pump, activated-carbon filters (ACFs), macrofilter, microfilter, UF units, piping system, measurement and control system and frame and installation.

Table 1
Chemical analysis of water samples before and after treatment in PFC, UF, BWRO plants

S. no.	Substance/or/ characteristic	Units	Inlet water to PFC treatment plant	Outlet water from PFC treatment plant	Influent water to UF treatment plant	Effluent water from UF treatment plant	Influent water to BWRO treatment plant	Outlet water from BWRO treatment plant
1	Color		Yellowish	Yellowish	Yellowish	Colorless	Yellowish	Colorless
2	Turbidity	NTU	65	45	45	45	45	5
3	pH-value	Unit	7.7	7.9	7.9	7.7	7.9	7.0
4	Conductivity	μmhos	3800	1700	1700	3800	1700	132
5	COD	mg/L	31	61	61	18	61	0
6	BOD-5	mg/L	23	41	41	14	41	0
7	SS	mg/L	19	121	121	10	121	0
9	TOC	mg/L	5.00	5.67	5.67	0.89	5.67	0
10	TDS at 105 °C	mg/L	2513	1247	1247	2513	1247	91.9
11	Sodium ion (Na^+)	mg/L	612	278	278	612	278	33.7
12	Potassium ion (K^+)	mg/L	16	7	7	16	7	1.095
13	Calcium ion (Ca^{2+})	mg/L	116	64	64	116	64	1.353
14	Magnesium ion (Mg^{2+})	mg/L	92	29	29	92	29	1.073
15	Chloride (Cl^-)	mg/L	943	386	386	943	386	40.744
16	Bicarbonate (HCO_3^-)	mg/L	328	181	181	328	181	258.024
17	Carbonate (CO_3^{2-})	mg/L	0	12	12	0	12	0.007
18	Hydroxyl (OH^-)	mg/L	0	0	0	0	0	0
19	Sulphate (SO_4^{2-})	mg/L	394	156	156	394	156	4.289
20	Silica (SiO_2), soluble	mg/L	7.86	9.11	9.11	7.86	9.11	0.28
21	Iron (Fe^{3+}), soluble	mg/L	1.49	0.54	0.54	1.49	0.54	0
22	Manganese (Mn^{4+}), sol.	mg/L	0.27	0.03	0.03	0.27	0.03	0
23	Phosphate (PO_4)	mg/L	2.01	2.98	2.98	2.01	2.98	0
24	Hardness (as $CaCO_3$)	mg/L	392	232	232	392	232	0
25	Total hardness	mg/L	734	401	401	734	401	0

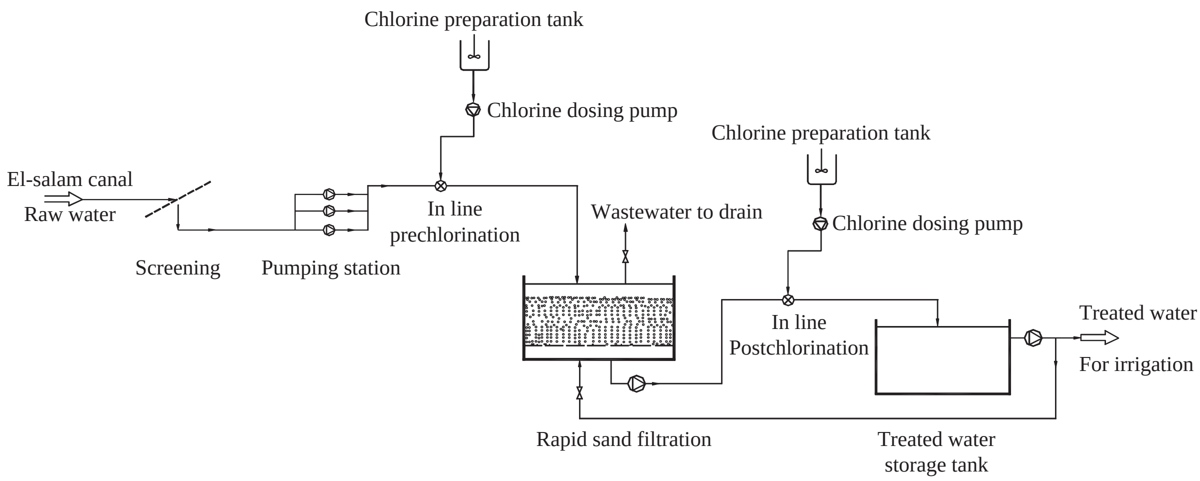

Fig. 1. Equipment flow diagram of pre-treatment plant.

2.2.3. Process description

The suggested operating system consists of: flocculation/coagulation, settling, primary chlorination, carbon filtration, secondary filtration, microfiltration, UF and final chlorination. The treated water from the PWFC treatment plant is pumped through pipe line to coagulators, where nonionic polymer is added with dose of 2.5 mg/L. The coagulator is consists of two parts: one for coagulation and the other where water flow to be settled. Percentages of SS, COD and TOC removal are as in Section 2.2.1. Chlorine is injected in the out let pipe line to disinfect the cleared water. The chlorinated water passes to ACF to remove the rest of dissolved organic matter and the free chlorine. The water is pumped to macro and microfilters to remove the escaped activated carbon, then to UF units. The filtered water is chlorinated for disinfection before using water for agricultural irrigation. The ACF operates under 3 bars, the micro and macrofilters operate at 1.5 bar and the UF units operate at 1.5–5 bar. Fig. 3 represents equipment flow diagram of UF plant.

2.2.4. Material balance

The plant material balance calculations are shown in Fig. 4 based on 1 h.

2.3. BWRO treatment plant

The capacity of the BWRO treatment plant is 2400 m^3/day. The productive water resulted from the BWRO treatment plant is distilled water of high quality, completely free from all organic, inorganic and biological pollutants. It is matching with WHO standard

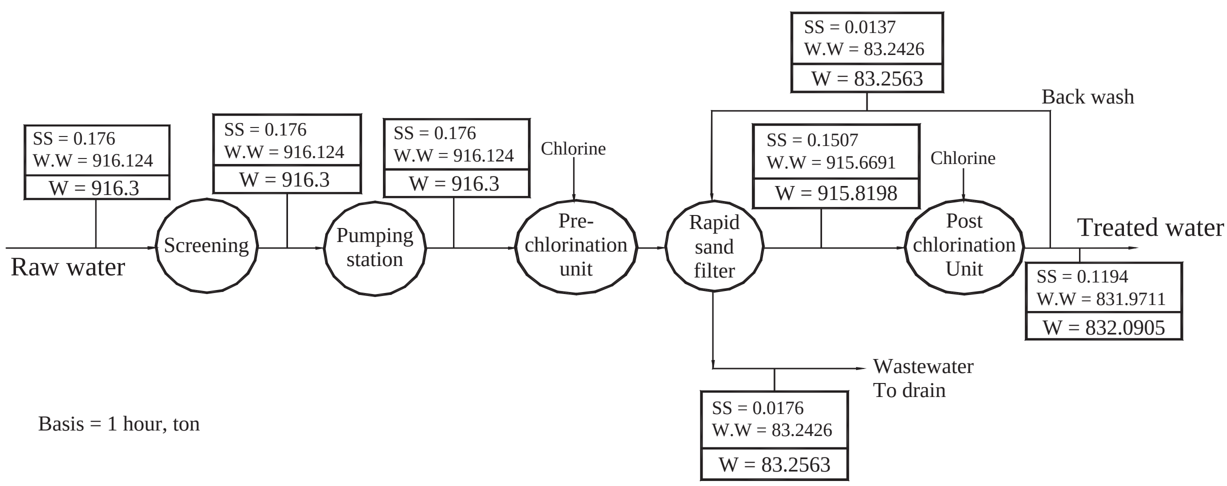

Fig. 2. Material balance of the pre-treatment plant.

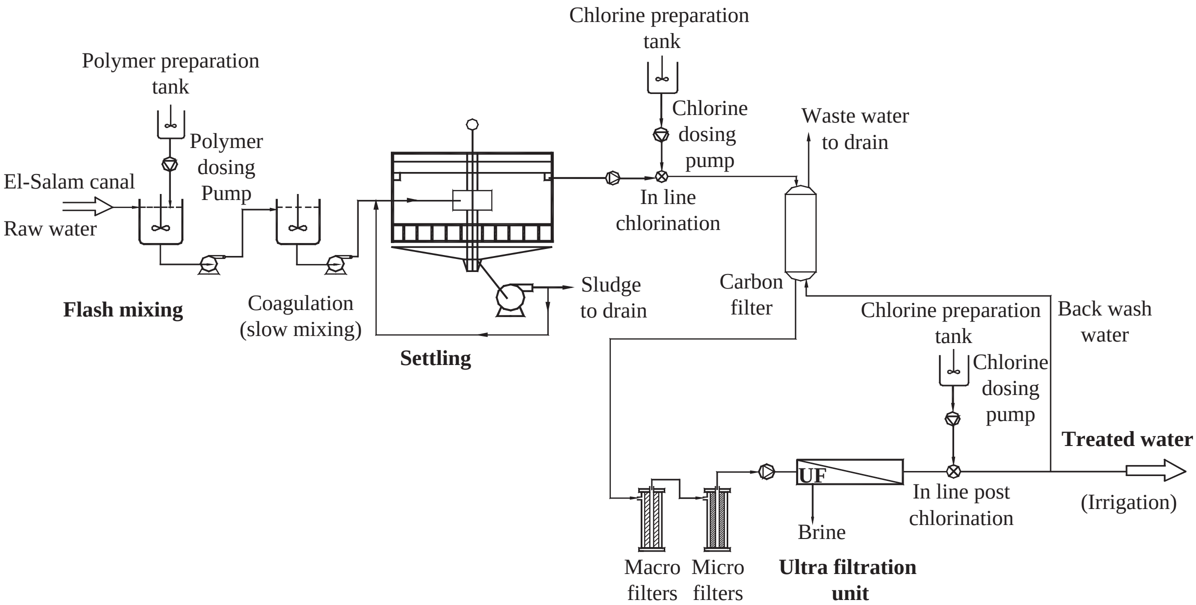

Fig. 3. Equipment flow diagram of ultrafiltration plant.

[5,6] for human drinking water and for industrial applications.

2.3.1. Design considerations

The design considerations are:

(a) The plant capacity is 2400 m^3/day.

(b) The characteristics of inlet water are the characteristics of the filtered and chlorinated water resulted from the PWFC treatment plant as presented in Table 2.

(c) Results of bench and pilot scale experiments which proved total removal of carbonate, 99%, 94% and 100% removal of hardness, iron ions and

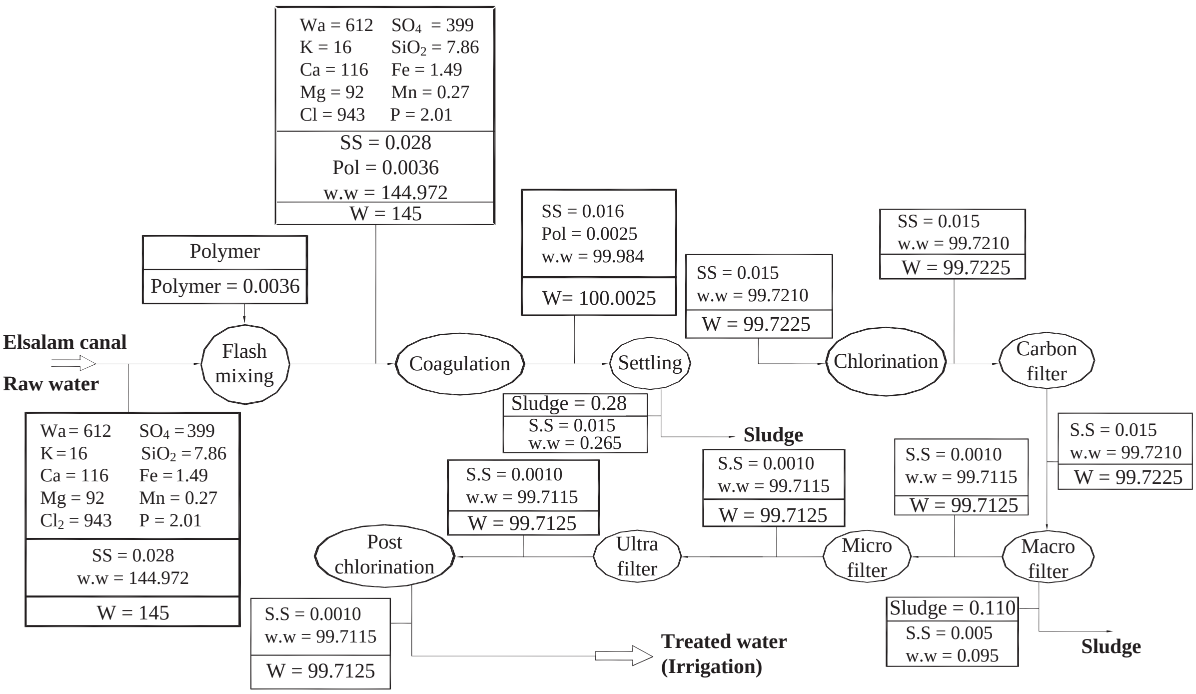

Fig. 4. Material balance of ultrafiltration plant.

Table 2
The annual operating for the PWCF, UF and SWRO treatment plants

	PWCF treatment plant	UF treatment plant	BWRO treatment plant
Raw materials	50	80	100
Electricity	30	30	50
Maintenance	97.09	121.59	225.12
Analyses	10	10	10
Management	138.7	173.70	321.6
Insurance	46.22	44.37	182.95
Depreciation	90.20	120.000	150.000
Labors	300.000	300.000	300.00
Total annual cost	462.21	443.66	1829.62

manganese ions, respectively. For rest ions, the divalent ions as calcium, magnesium and sulphate were removed completely. The monovalent ions such as sodium removed by 97.99 and potassium ions removed by 78.56%. The mono and trianionic such as chloride, bicarbonate and phosphate were removed by 98%.

2.3.2. Plant components

The plant components are: pumping station, coagulation/flocculation and settling unit, chemical preparation units, chlorination building, chlorine dosing pump, iron and manganese unit, sand filter, ACFs, de-chlorination unit, feeding pump (2–4 bars), macrofilter, microfilter, backwash unit, high pressure pump, RO modules, flushing system, final permeate storage tank, concentrate tank, piping system, measurement and control system, electricity station and frame and installation. Fig. 5 represents equipment flow diagram of RO plant.

2.3.3. Process description

The operating system consists of: flocculation/coagulation, settling, acidification, primary chlorination, iron and manganese removal, sand filtration, carbon filtration, de-chlorination, silica antiscaling, macrofiltration, microfiltration, RO separation and final chlorination. The process description is as follows: the treated water from primary treatment plant is pumped through pipe line to coagulators, where nonionic polymer is added with dose of 2.5 mg/L where the rest of SS, COD and TOC are removed. Clarified water is

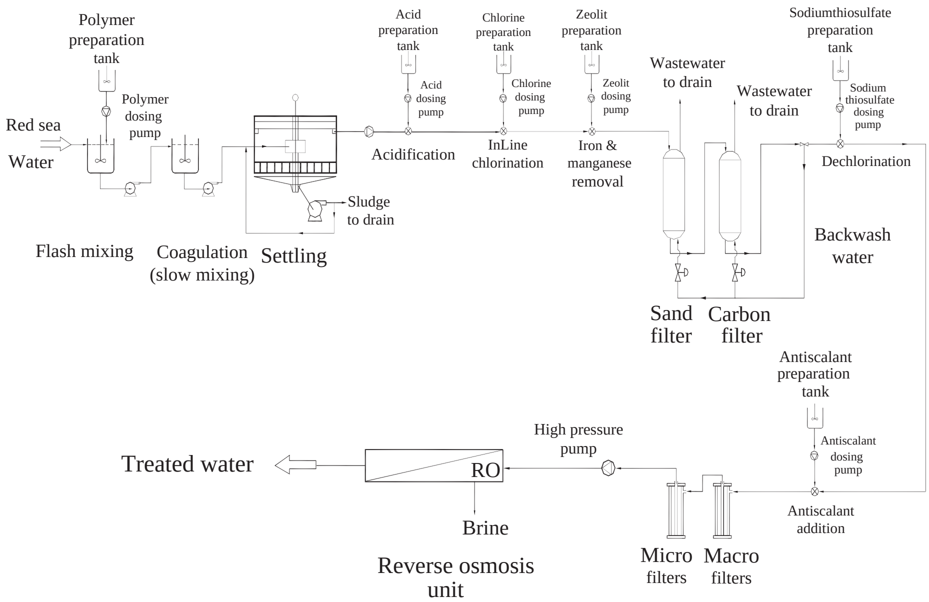

Fig. 5. Equipment flow diagram of reverse osmosis (RO) plant.

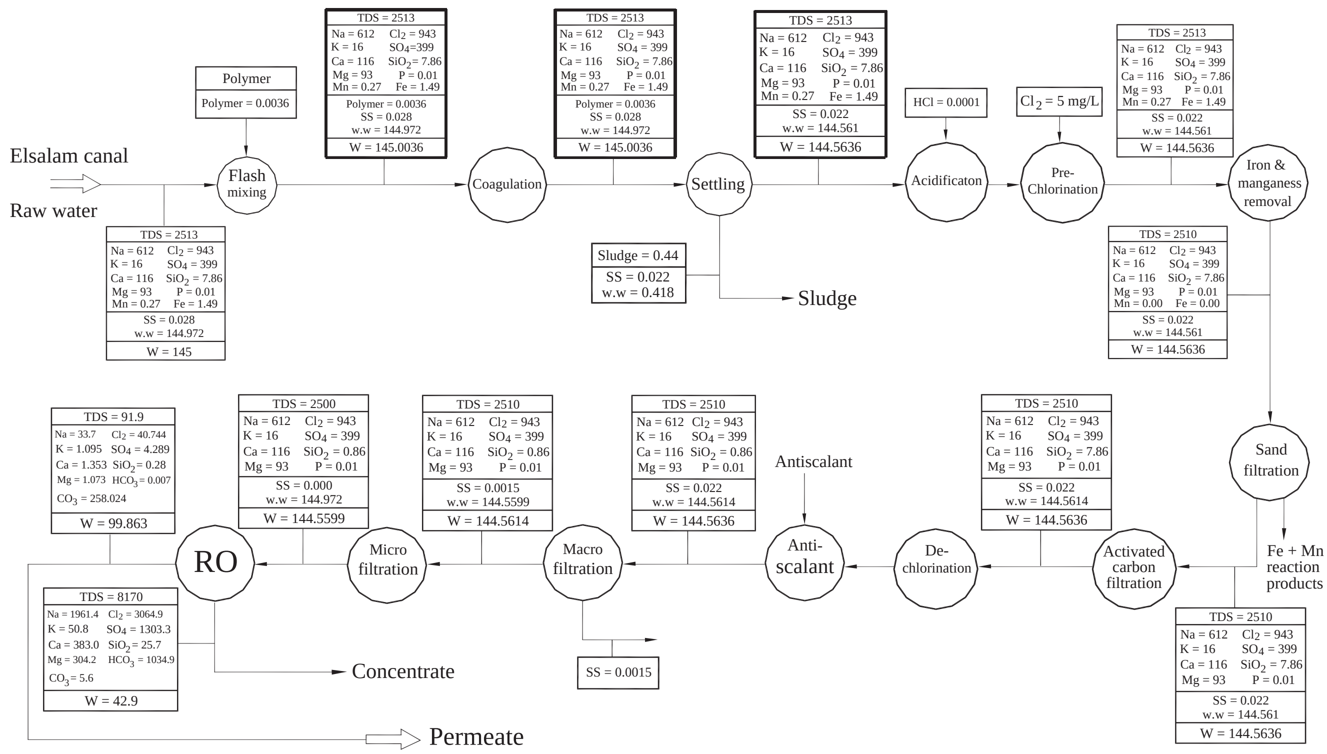

Fig. 6. Material balance of reverse osmosis plant.

injected by hydrochloric acid of 5 mg/L and free chlorine for contact time of 45 min to disinfect the cleared water and kill all viruses and bacteria. The chlorinated water passes to iron and manganese filter operate under 3 bars, which filled with natural zeolite to absorb nearly all ions of iron and manganese. The zeolite is regenerated by using potassium permanganate. The outlet water will pass to sand filter and ACF then dechlorination is carried out by adding sodium bisulphate. The antiscaling is added and water is pumped to macrofilter to remove fine particles, microfilter to remove colloidal and microscopic particles and to act as final polishing. The water then passes to the RO units where permeate and concentrate are collected. The RO units operate under 16 bars.

2.3.4. Material balance

The plant material balance calculations are shown in Fig. 6 based on 1 h. Table 1 represents the characteristics of water samples before and after treatment in PWFC, UF and BWRO plants.

3. Economic study

The economic study of the complex treatment plant which consists of three plants PCF, UF and BWRO is investigated. The economic study for each plant is consists of the total fixed capital cost, annual operating cost and cost of one cubic meter resulted from treatment plant. The fixed capital cost represents the costs of equipment, equipment erection, piping and insulation, instrumentation and control, electrical utilities, land price, engineering and procurement, emergency and contingency. The annual operating cost includes: raw materials, electricity, analyses, management, insurance, depreciation, maintenance and labors. The cost of one cubic meter is consists of total fixed capital cost and operating cost for 3 months based on the cycle of production of water and selling it dividing by the capacity of each plant. Tables 2 and 3 represent the fixed capital cost and the operating cost. The operating costs for 3 months are 115,500, 145,890 and 457,450 L.E. for PFC, UF and BWRO plants, so the cost of one cubic treated water resulted from PFC, UF and BWRO plants are 0.4 L.E (0.07 U$), 3.7 L.E(0.67 U$) and 7.38L.E (1.34 U$), respectively.

5. Conclusion

Complex treatment plant is proposed which consists of three types of plants: PWFC treatment plant of 20,000 m^3/day capacity, UF water treatment plant of 2400 m^3/day capacity and BWRO treatment plant of

Table 3
The fixed capital cost for the PWCF, UF and SWRO treatment plants

	PWCF treatment plant	UF treatment plant	BWRO treatment plant
Item	Estimated cost in 1000 L.E.		
Equipment cost	1387.000	1737.000	3216
Equipment erection 20% of equipment cost	277.400	347.400	634.2
Instrument and control 15% of erection cost	41.610	52.110	95.13
Piping and insulation 30% of erection cost	83.220	104.220	190.26
Electrical utilities 10% of equipment erection	27.740	34.740	63.40
Land price	50.000	50.000	50.00
Site preparation	27.740	34.740	63.40
Engineering and procurement 20% of equipment cost	277.740	347.400	634.20
Emergency 10% of fixed capital cost	250.590	281.500	570.76
Contingency 30% of equipment cost	83.220	104.220	190.26

2400 m^3/day capacity. Techno-economic study proved that the fixed capital costs of the PWFC, the UF and BWRO are 2,502,000, 2,815,460 and 3,216,000 L.E., respectively. The annual operating costs are 115,500, 443,660 and 1,829,620 L.E. and the cost of one cubic meter treated water is 0.4, 3.7 and 7.38 L.E. for PWFC, UF and BWRO, respectively.

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