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Assessment of Wastewater Reuse Potential for an Enamel Coating Industry

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Abstract**—**In order to eliminate water scarcity problems, effective precautions must be taken. Growing competition for water is increasingly forcing facilities to tackle their own water scarcity problems. At this point, application of wastewater reclamation and reuse results in considerable economic advantageous. In this study, an enamel coating facility, which is one of the high water consumed facilities, is evaluated in terms of its wastewater reuse potential. Wastewater reclamation and reuse can be defined as one of the best available techniques for this sector. Hence, process and pollution profiles together with detailed characterization of segregated wastewater sources are appraised in a way to find out the recoverable effluent streams arising from enamel coating operations. Daily, 170 m^3 of process water is required and 160 m^3 of wastewater is generated. The segregated streams generated by two enamel coating processes are characterized in terms of conventional parameters. Relatively clean segregated wastewater streams (reusable wastewaters) are separately collected and experimental treatability studies are conducted on it. The results reflected that the reusable wastewater fraction has an approximate amount of 110 m^3/day that accounts for 68% of the total wastewaters. The need for treatment applicable on reusable wastewaters is determined by considering water quality requirements of various operations and characterization of reusable wastewater streams. Ultra-filtration (UF), Nano-filtration (NF) and Reverse Osmosis (RO) membranes are subsequently applied on reusable effluent fraction. Adequate organic matter removal is not obtained with the mentioned treatment sequence.

Keywords**—**Enamel coating, membrane, reuse, wastewater.

I. Introduction

WITHIN the next 15 years, industrial water consumption is expected to reach 1500 billion m^3 at the global level [1]. On the other hand, currently Turkish industry requires 5 billion m^3 water input per year which accounts for 11% of the total water consumption of the country [2]. The projections stated that the amount of industrial water requirement will rise up to approximately 22 billion m^3 in Turkey in the next 15 years [3]. When the numbers presented here are evaluated with the accelerated industrial development of the country and the uneven distribution of the water resources, it is evident that necessary precautions have to be taken proactively. In order to solve the future problems related to industrial water scarcity, industrial sectors with intensive water requirements must be targeted. In some cases, apart from obtaining environmental benefits, the application of wastewater reclamation and reuse results in economic gains too. Successful applications of wastewater reclamation and reuse to a wide range of industrial sectors such as textile mills, gas refineries, coking plants, soft drink manufacturing facilities, metal finishing etc. are reported in literature [3]-[8].

Enamel coating facilities can be regarded as industries with high water consumption. Wastewater reclamation and reuse applications are quoted among the best available techniques defined for this sector [9]. A case wise assessment is required to get fruitful results.

In this study, an enamel coating facility is evaluated in terms of its wastewater reuse potential. For this purpose, process profiles together with pollution profiles are investigated by performing a detailed quantitative and qualitative characterization of the wastewater sources. The composite wastewater sample that represents the combination of reusable segregated effluent streams is then subjected to UF, NF and RO. The results obtained are investigated by considering the process water quality requirements.

II. Materials and Methods

A. Wastewater Characterization and Treatability for Reuse

All the segregated wastewater samples were obtained from a facility that performs enamel coating operations. The conventional wastewater characterization was performed on the segregated effluent streams of two different enamel coating processes (Enamel I, Enamel II). In the characterization study, conductivity, pH, total organic carbon (TOC), Fe, oil and grease, calcium, magnesium, hardness, silicon, chloride, nitrite and nitrate measurements were carried out on grab wastewater samples collected from individual discharge points (segregated effluents) [10]. The chemical oxygen demand (COD) measurements were conducted according to ISO6060 [11]. The wastewater characteristics were evaluated by considering the flowrates and quality requirements of process waters (Softened and distilled (DI) water).

Based on the mentioned evaluation, a flow proportional composite reusable wastewater sample (named as Enamel Composite) was prepared.

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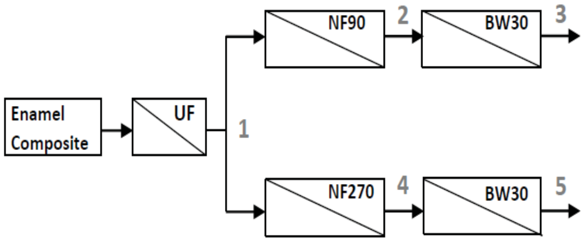

Fig. 1 Sequential membrane treatability route for reuse

A membrane treatability study that comprised of the sequential application of UF, NF and RO membranes was conducted to increase the quality of the Enamel Composite (Fig. 1). After passing the Enamel Composite from UF filtration (using UF010 membranes), the obtained permeate was directed to two different treatment alternatives: i) sequential application of NF90 and BW30; and ii) sequential application of NF270 and BW30 membranes. The inlet pressure before UF, NF and BW30 membranes were adjusted to 3, 10 and 20 bars with adjustable pressure pump, accordingly.

III. Results and Discussion

A. Process and Pollution Profiles

In the plant metal sheets that are previously passed through various surface pre-treatment processes are subjected to enamel coating to bring more thermal resistance to the product. In the enamel coating facility 170 m^3 of process water is required and 160 m^3 of wastewater is generated.

As can be seen from Figs. 2 (a) and (b), there are two parallel enamel coating units: Enamel I and Enamel II, respectively. The first one operates daily on one shift basis, whereas the latter has a continuous nature. As given in Fig. 2, in both lines there are continuous water requirements together with intermittent ones that are mainly applied for cleaning purposes, resulting in continuous and intermittent wastewater generations. Tables I and II outline the results of the segregated wastewater characterization of Enamel I and Enamel II, respectively.

For both enamel lines the segregated wastewater streams with code C-2 are selected as the most appropriate candidates for effluent reuse. Therefore, these continuous effluents are quoted as reusable wastewaters. There are certain segregated effluent streams (such as I-9 in Enamel I) with low pollutant contents, however as these streams are intermittent ones with relatively low flowrates, they are not included in the reusable fraction. The reusable wastewater fraction has an approximate amount of 110 m^3/day that accounts for 68% of the total wastewaters.

B. Treatability Results

As mentioned earlier Enamel Composite sample is prepared by mixing wastewater discharges of Enamel I and II tagged with “C2” as shown in Figs. 2 (a) and (b). The reason of selecting those wastewater streams are (1) having the highest flowrate (653.4 m^3/week) and (2) lowest pollutant concentrations (Tables I and II). It should be noted that the selected streams have the minimum organic carbon concentration (Table III). The composite sample has high pH (9.2) and organic matter content (660 mgCOD/L). The TOC concentration of composite was determined as 355 mgC/L. The COD/TOC ratio is calculated as 1.85 in the composite sample. The columns given on the right hand of Table III summarizes the required general water quality used in enamel processes. The comparison of composite wastewater and softened water shows that conductivity and COD parameters are higher than that of softened water. The UF filtration is not sufficient to fulfill the criteria, however, NF application could only meet the conductivity, but the COD parameter is not complied. Application of subsequent RO is not sufficient for the removal of organic matter from wastewater.

The COD levels could only reduce to 82 and 90 mg/L in RO permeates (BW30). It is important to note that the wastewater still contains COD together with relatively high conductivity levels of around 70-102 µS/cm. This phenomenon supports the theory of interaction between biofouling and salt rejection during RO treatment [12]-[14]. In summary, conductivity in permeate can be attributed to the organic polymeric substances which may influence the diffusion of charged substances across the RO membrane. The DI water quality required in the process needs further removal of conductivity and organic matter even after RO treatment. As a result, organic carbon removal (membrane bioreactor, chemical oxidation etc.) is required to remove remaining unwanted organic matter. In addition, it is also expected to reduce conductivity when organic matter is removed via pretreatment methods before entering RO.

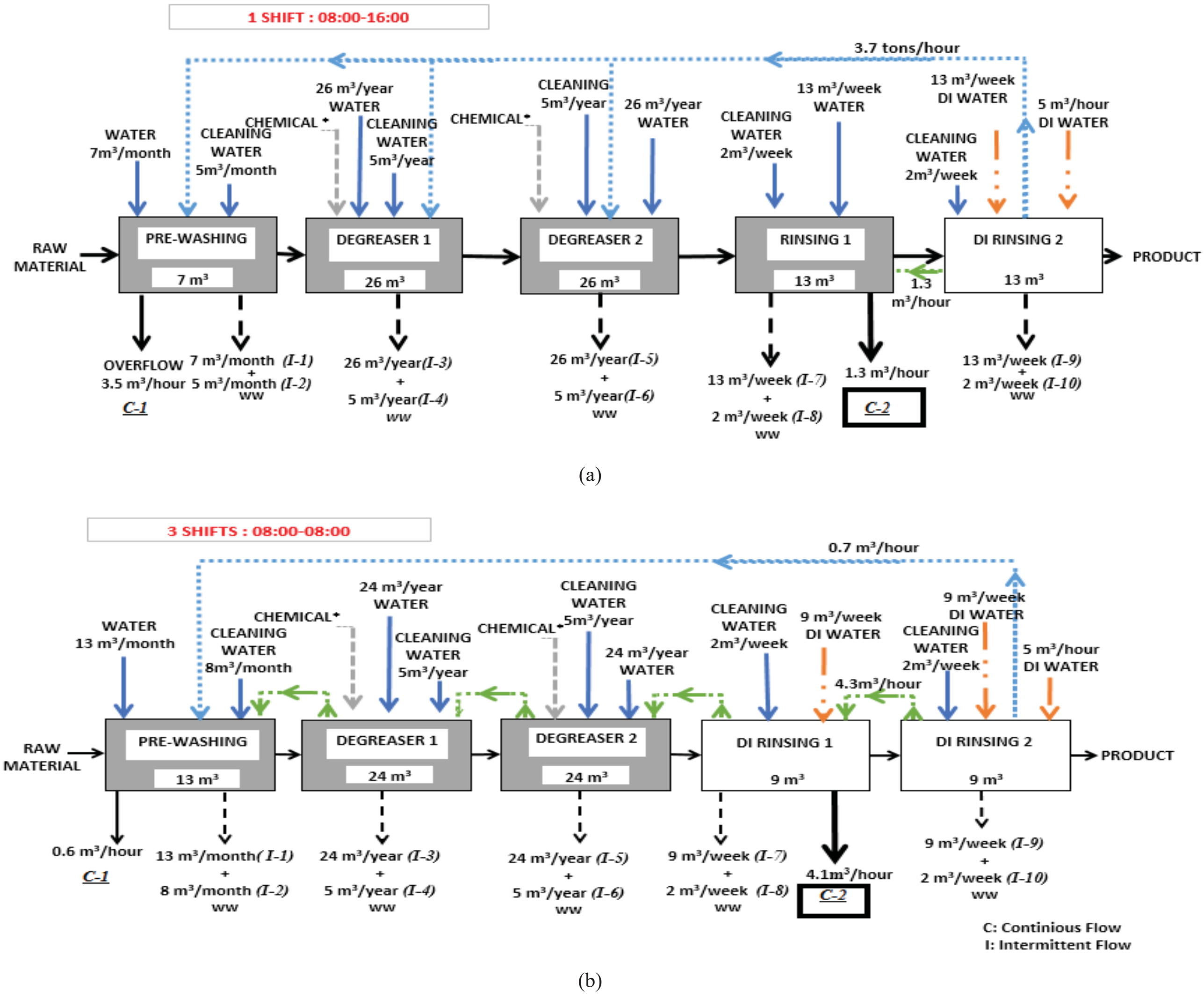

Fig. 2 Process Flowcharts of Enamel I (a) and Enamel II (b)

TABLE I
SEGREGATED WASTEWATER CHARACTERIZATION OF ENAMEL I

Parameter	Unit	Segregated Effluent Code						
		C-1	I-1	I-7	I-8	C-2	I-9	I-10
Flowrate	m^3/week	168	1.62	13	2	***62.4***	13.0	2.0
pH	-	7.69	7.74	6.81	7.31	***7.05***	7.76	7.63
Conductivity	µS/cm	564	633	292	476	***329***	58	163
TOC	mg/L	225	103	33	131	***130***	2.3	11
T.Fe	mg/L	2.2	-	-	-	***2.0***	-	-
Oil & Grease	mg/L	745	80	22	139	***25***	57	16
Ca	mg/L	5.0	-	-	-	***7.0***	-	-
Mg	mg/L	1.0	-	-	-	***1.0***	-	-
T.Hardness	mg $CaCO_3$/L	16	-	-	-	***22***	-	-
Si	mg/L	2.5	-	-	-	***<0.06***	-	-
Chloride	mg/L	6.8	6.6	5.1	42.9	***12.2***	3.7	12.7
Nitrite	mg NO_2/L	<1.0	<1.0	<1.0	<1.0	***<1.0***	<1.0	<1.0
Nitrate	mg NO_3/L	<1.2	<1.2	14.4	<1.2	***<1.2***	2	10.8
Phosphate	mg PO_4/L	<2.0	<2.0	2.0	<2.0	***<2.0***	<2.0	<2.0
Sulfate	mg/L	4.5	3.9	3.5	11	***6.1***	1.7	5.1

TABLE II
SEGREGATED WASTEWATER CHARACTERIZATION OF ENAMEL II

Parameter	Unit	Segregated Effluent Code							
		C-1	I-1	I-2	I-7	I-8	C-2	I-9	I-10
Flowrate	m^3/week	86.4	3.0	1.85	9.0	2.0	***590.4***	9.0	2.0
pH	-	7.93	8.20	7.81	7.43	8.36	***9.67***	7.28	7.44
Conductivity	µS/cm	1427	1411	1633	441	658	***506***	263	752
TOC	mg/L	1163	3255	1516	250	220	***381***	120	131
T.Fe	mg/L	8.53	-	-	-	-	***3***	-	-
Oil and Grease	mg/L	445	68	398	48	198	***20***	32	114
Ca	mg/L	7.0	-	-	-	-	***7.0***	-	-
Mg	mg/L	1.0	-	-	-	-	***1.0***	-	-
T.Hardness	mg $CaCO_3$/L	22	-	-	-	-	***20***	-	-
Si	mg/L	14	-	-	-	-	***0.5***	-	-
Chloride	mg/L	7.0	-	9.8	4.4	72.4	***3.4***	4.2	55.2
Nitrite	mg NO_2/L	<1.0	-	<1.0	<1.0	<1.0	***<1.0***	<1.0	17.3
Nitrate	mg NO_3/L	<1.2	-	<1.2	<1.2	29.1	***<1.2***	<1.2	21.5
Phosphate	mg PO_4/L	<2.0	-	<2	<2	28	***<2***	<2	<2
Sulfate	mg/L	10.3	-	22.3	3.1	146.3	***3.8***	2.1	81

TABLE III
THE RESULTS OF MEMBRANE TREATMENT

Parameter	Unit	Enamel (Composite)	Permeate					Water Quality Criteria	
			1	2	3	4	5	SoftenedWater	DI Water
Flowrate	m^3/day	108.8							
pH		9.2	9.3	7.2	7.2	8.7	8.2	6.5-10	5.5-8.5
Conductivity	µS/cm	615	572	223	102	265	70	160-450	<20
COD	mg/L	660	293	186	80	169	92	<30	<30
T.Fe	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0-0.5	0- 0.1
Ca	mg/L	6.0	-	<1.0	<1.0	<1.0	<1.0	<40	0.20
Mg	mg/L	0.63	-	<0.2	<0.2	<0.2	<0.2	<24	0.12
T.Hardness	mg $CaCO_3$/L	17.6	-	-	-	-	-	180	0.5
Chloride	mg/L	5.6	-	5.0	2.0	5.0	1.7	75	0-5
Nitrate	mg NO_3/L	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2	0-30	0-5
Phosphate	mg PO_4/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	0-30	0-5
Sulfate	mg SO_4/L	4.4	-	4.13	3.40	3.84	2.62	250	0-5

IV. CONCLUSIONS

The following results are obtained in this study:

i) The enamel coating operations 170 m^3/day of process water is used and as a result 160 m^3/day of wastewater is generated.

ii) Experimental wastewater characterization study conducted on segregated effluent discharges showed that approximately 110 m^3/day of wastewaters accounting for 68% of the total effluents can be quoted as reusable.

iii) The reusable composite wastewater has conductivity and COD parameters that are higher than that of the required softened water quality. UF filtration is not sufficient to fulfill these criteria. With subsequent NF application only conductivity requirement can be met but still COD level is not complied. Besides application of RO after NF is not sufficient for the removal of organic matter from wastewater.

iv) Organic matter removal is recommended prior to apply membrane treatment for obtaining a quality suitable to reuse the wastewaters in Enamel processes.

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