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Research Article

Characterisation of aluminium industrial wastewater and investigation of recovery alternatives

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ABSTRACT

Aluminium industry is one of the largest sectors and wastewater generated from this industry could cause crucial environmental problems due to its high heavy metal concentration and conductivity. Therefore, this study aims to determine the characterisation of the wastewater discharged from the two aluminium facilities by considering water recovery potential. While Facility-A produces stainless steel kitchenware, such as pots and pans, In Facility-B, anodised coating takes place from secondary aluminium and wastewater is generated from the units where anodised coating baths and control processes are carried out. For the analyses, the wastewater composite samples from different sections, such as washing, sand-blasting and dyeing in Facility-A were taken in 2 and 24 hours. In Facility-B, three 2-hour composite influent water samples and an effluent sample from chemical wastewater treatment were taken to determine conductivity, pH, chemical oxygen demand (COD), total suspended solids (TSS), etc. As a result of the analyses made, a high value of TSS was detected at all sampling points in Facility-A. It was also seen that the conductivity after demineralisation process in Facility-A was below 30. In Facility-B, it was determined that while the pH obtained from two influent samples was below the discharge limits and showed acidic characteristics, one sample was very basic with a pH value of 12.19 and exceeds the upper limit of discharge. All influent samples in Facility-B show high TSS content in comparison with discharge limits specified in the regulation.

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INTRODUCTION

Aluminium is one of the most widely used metals due to its high strength, corrosion resistance, heat and electrical conductivity [1, 2]. Depending on the development of the aluminium industry, facilities processing aluminium are increasing worldwide. However, the wastewater discharged from these facilities remains an important environmental problem [3, 4]. Significantly, high water costs,

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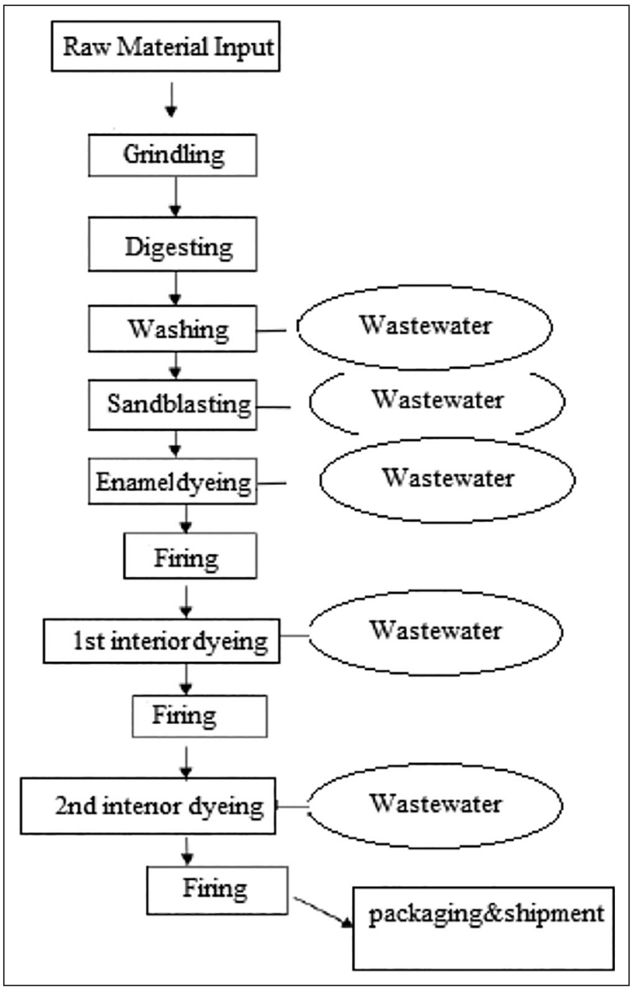

Figure 1. Flow chart of Facility-A.

restrictions on water use, and sanctions to improve environmental conditions have also made water recovery systems attractive to be used efficiently in the industrial sector [5–8].

In aluminium industry, heavy metal content, pH, colour, conductivity, total suspended solids (TSS) and chemical oxygen demand (COD) of the wastewater vary depending on an applied process and amount of aluminium coating [7, 8]. As wastewater produced from various stages (such as washing, dyeing, anodising etc.) has toxic and complex characteristics, it requires the development and use of efficient treatment methods [8–14].

In the aluminium industry, coating and matting are the stages which result in the generation of wastewater rich in aluminium, zinc and chromium [9]. So far, various methods have been used to remove metals from wastewater discharged from the aluminium industry, such as membrane filtration, chemical precipitation, electro-dialysis, electro-deionisation, valorization, and nanotechnology [9–11]. Various shells were also investigated for the efficient removal of aluminium from water [12]. However, it was proven that the efficiency of these methods is based on the determination of the characteristics of the wastewater [15–19]. For example, characteristics of treated effluent from several wastewater treatment plants in the UK were investigated to assess whether differences in nutrient export could be detected by these plants [20]. Two different wastewater samples were characterised to explore the potential for their recovery [21]. Accordingly, the characterisation of wastewater discharged from the pharmaceutical industry was carried out to evaluate the efficiency of bioremediation as a sustainable technique [22]. However, in the national literature, the aluminium sector-based studies usually focus on the determination of characteristics of red mud which is produced in large amounts and could be reused in various sectors, such as cement production [23–26].

Therefore, this study aims to determine the characterisation of the wastewater discharged from the aluminium sector by considering water recovery potential. In this study, the wastewater discharged from two different aluminium facilities was characterised by using the parameters such as conductivity, pH, COD, TSS, etc. To evaluate recovery potential, the applicability of various treatment methods, such as demineralisation, ultrafiltration and reverse osmosis for the removal of pollution in the wastewater was discussed. The content of this manuscript includes the introduction, methods and materials which include the details of the facilities where the work is carried out, the results and discussion in which the analysis results are presented and discussed and then the conclusion part.

MATERIALS AND METHODS

Facility-A produces stainless steel kitchenware such as pots and pans. During the production of non-stick kitchen utensils, after the forming process is completed, the products are taken to the washing line (Fig. 1). In this stage, an average of 11 m^3/day of water is used. The water coming out of the washing section accumulates in the balancing pool and from there it is sent to the settling tank for chemical treatment. In addition, water is used for cleaning the dyeing units (1^{st} and 2^{nd} interior dyeing), which are cleaned every ten days. The wastewater generated from the dyeing process is sent to the treatment plant. It is taken to the industrial wastewater collection pool through the wastewater collection channels within the facility. The wastewater is then pumped into the chemical reactor with the centrifuge. After the chemical treatment process is carried out in the chemical reactor tank, the wastewater is taken to the pre-storage tank. The wastewater is passed from this tank through the sand and active carbon filter tanks, respectively, by a booster pump. After this, the treated wastewater is taken to the clean water tank.

Figure 2. Demineralisation unit in Facility-A.

In Facility-A, water recovery is carried out by demineralisation method as it is both economical and reduces conductivity efficiently. In the demineralisation unit, filter tanks made of different types of materials are applied depending on the characteristics of the water. In addition, multi-way valves (SIATA or FLEG), manual, pneumatic diaphragm valves are employed. Granular activated carbon, anionic and cationic resin are used as filling materials in demineralisation filters. Demineralisation units work automatically as in all other treatment systems. The automation of these filters is provided by different ways and equipment.

This system within Facility-A is automatically controlled by the control panel as shown in Figure 2. The control panel of the system allows manual intervention to the desired equipment and/or unit. There is a manual start button on the control panel of the system so that the filters can start the manual regeneration and a manual phase bypass button is available to enable the filters to pass to the next phase during regeneration. If any unit fails for any reason, the system is automatically disabled. The control panel of the system gives a visual warning in case of malfunction and the description of the malfunction is indicated on the operator panel. In addition, there is a reset button on the control panel of the system.

The demineralisation unit consists of two columns. The first column includes cationic resin and removes positively charged metal ions such as Ca^{+2}, Mg^{+2}, Na^{+1}, Fe^{+2} and Mn^{+2}. When charged ions adhere to the exchange material, they leave as many hydrogen ions as their charge. Due to the increase of hydrogen ions, the amount of acid in the solution increases. At this point, half of the deionisation process is completed. The positively charged metal ions are purified and this leaves hydrogen ions and anions in the solution. In the second column, there is an anionic resin which absorbs the negative ions, such as HCO_3^-, Cl^-, SO_4^{-2} in the solution. When the resin is saturated (it can be understood immediately from the conductivity value in the effluent), the regeneration process is performed with a base. As a result of regeneration, hydroxide is released into the resin. In this case, H^+ ions remain from the first stage and OH^- ions emerging in the second stage in the solution. These combine to form a water molecule. As a result, mineral-free water is obtained at the end of this process.

In Facility-B, anodised coating takes place from secondary aluminium and wastewater is generated from the units where anodised coating and control processes are carried out (Fig. 2). Grid systems are placed at the entrance of the balancing pools for industrial wastewater coming from different points originating from the facility. Wastewater is collected in the balancing pool after passing through the screen. In the three existing balancing pools, the flow oscillations in the wastewater are balanced and the treatment plant is fed at an equal flow rate throughout the day. Figure 3 gives a schematic view of Facility-B.

Facility-B produces 600 m^3 of wastewater per day. The wastewater produced from the use of employees is collected in a separate balancing pool and treated in the biological treatment unit. 1000 people work in the facility and the wastewater produced from internal activities within the plant is approximately 200 m^3 per day.

In Facility-B, before the anodising process, the profiles are subjected to a series of processes such as sanitation and digesting in matting baths. Matting baths provide a satin/mattified appearance on the surface of the profiles.

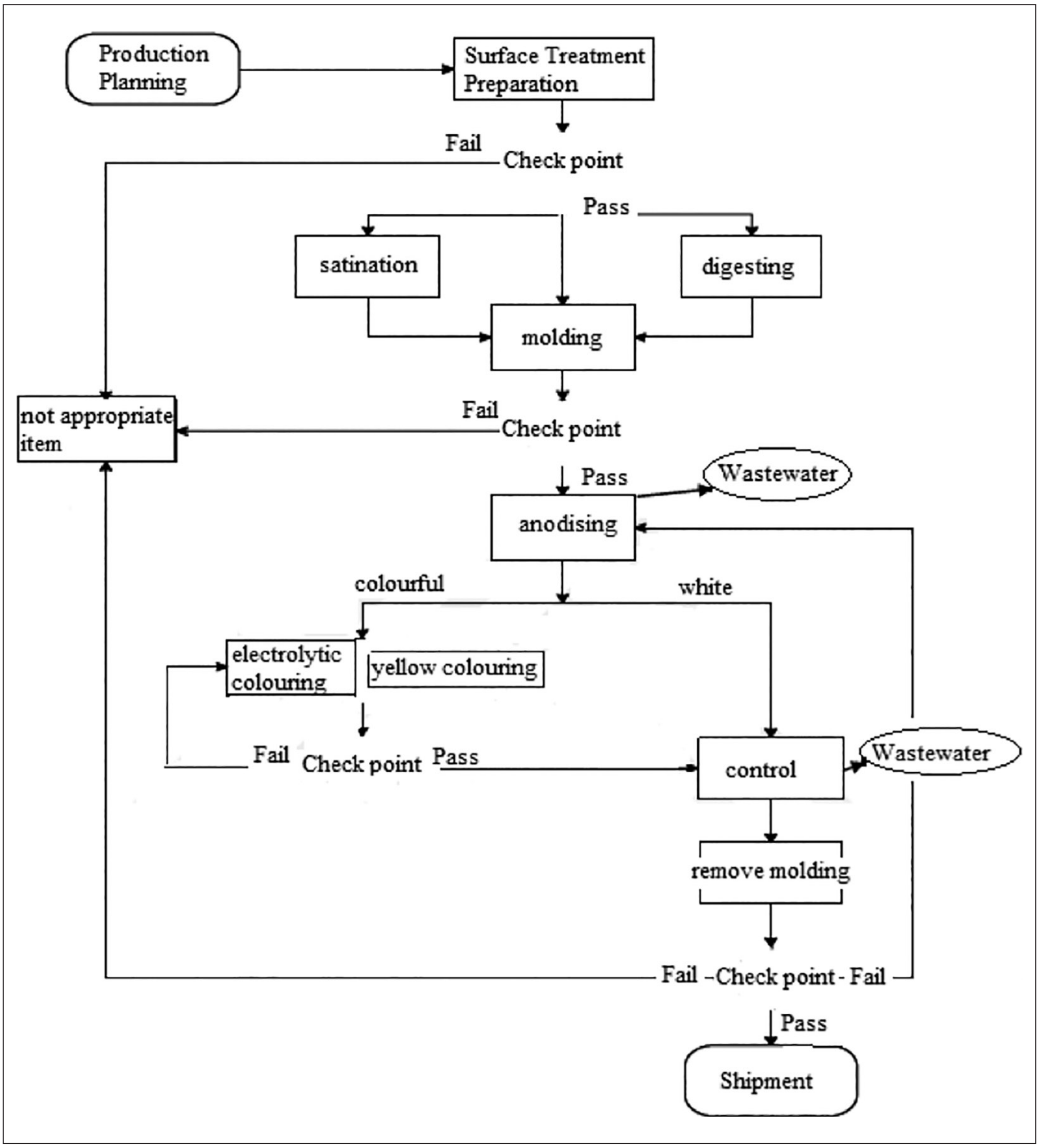

Figure 3. Flow chart of Facility B.

For the analyses, the wastewater composite samples from different sections, such as washing, sand-blasting and dyeing in Facility-A were taken in 2 and 24 hours. In Facility-B, three 2-hour composite influent water samples and an effluent sample from chemical wastewater treatment were taken to determine conductivity, pH, COD, TSS, etc. The values of the parameters were determined by using various methods provided by the Turkish Standards (TS EN ISO 10523), Standard Methods for the Examination of Water and Wastewater (SM 2540 D and SM 5220 B) as detailed in the Results and Discussion section.

RESULTS AND DISCUSSION

The wastewater composite samples from washing, sand-blasting and dyeing in Facility-A were taken in 2 and 24 hours and the values of the parameters, such as colour, pH, conductivity, COD, TSS, etc. were determined and shown in Table 1. As a result of the analyses made, high TSS was detected at all sampling points as shown in Table 1. It is known that ultrafiltration and reverse osmosis methods could be beneficial to eliminating TSS efficiently from wastewater [27]. However, these methods also inherit a high cost for treatment [28].

Table 1. Results of the wastewater analyses in Facility-A

Parameters	Analysis method*	Wastewater from washing section	Wastewater from sand-blasting	Wastewater from 1st interior dyeing	Wastewater from enamel dyeing	Wastewater from 2nd interior dyeing
Colour	–	Dark brown	Black	Grey	Pink	Yellow
Appearance	–	–	Dense and particulate	Dense and particulate	Particulate and turbid	Oily
pH	TS EN ISO 10523	7.35	9.5	7.8	9.8	11.7
Conductivity (µS/cm)	pH meter**	3100	1375	3000	1423	7250
COD (mg/L)	SM 5220 B	>10000	>10000	>10000	464	>3500
TSS (mg/L)	SM 2540 D	541	>750	>750	-	164
Total ferrous (mg/L)	EPA 200.7:2001	29.5	>50	>50	1.4	20
Nickel (mg/L)	EPA 200.7:2001	10.6	>50	>50	2.9	5.5
Aluminium (mg/L)	EPA 200.7:2001	1.2	>6	7.8	4.75	5.65

*: EPA: Environmental Protection Agency; SM: Standard Methods for the Examination of Water and Wastewater; **: Water Quality Meter Temp Log 8603.

Table 2. Results of the further wastewater analyses in Facility-A

Parameters	Influent in settling tank	Effluent of chemical reactor	Effluent after demineralisation	Limits for reusability [29]
Conductivity (µS/cm)	2250	2000	15	<30
COD (mg/L)	187	87.96	45	<50
Ferrous (mg/L)	<10	<10	<10	<10
Aluminium (mg/L)	0.55	0.1	<0.1	<0.1
pH	8.85	7.31	7.05	6–9

Table 3. Results of the wastewater analyses in Facility-B

Parameters	Analysis method*	Sample 1	Sample 2	Sample 3	Sample 4	Discharge limit values [29]
Conductivity (µS/cm)	pH meter**	25000	26123	24261	20400	–
pH	TS EN ISO 10523	4.08	12.19	3.62	6–9	6–9
COD (mg/L)	SM 5220 B	202.6	232.0	247.4	114	100
TSS (mg/L)	SM 2540 D	4886	5270	5716	98	125
Oil-Grease (mg/L)	SM 5520 D	<10	<10	<10	<10	20
Nitrogen (mg/L)	SM 4500 NO2 B	0.03	0.2	0.025	<5	5
Active chlorine (mg/L)	SM 4500 CI-G	0.03	0.03	0.033	<0.5	0.5
Total chrome (mg/L)	EPA 200.7:2001	0.054	0.018	0.163	<1	1
Chrome (mg/L)	SM 3500 Cr:B	<0.02	<0.02	<0.02	<0.02	0.5
Aluminium (mg/L)	EPA 200.7:2001	277679	350125	686549	<3	3
Fluoride (mg/L)	SM 4500 F-D	<0.1	0.53	<0.1	<0.1	50
Ferrous (mg/L)	EPA 200.7:2001	2.553	0.014	5.677	<3	3
Nickel (mg/L)	EPA 200.7:2001	0.082	<0.003	0.154	<0.003	2
Zinc (mg/L)	EPA 200.7:2001	0.056	<0.0006	0.166	<0.0006	3
Colour (Pt-Co)	SM 2120 C	<5	18.5	8	<5	280

*: EPA: Environmental Protection Agency; SM: Standard Methods for the Examination of Water and Wastewater; **: Water Quality Meter Temp Log 8603.

As a further step, the analyses of the wastewater taken from the various sampling points, such as the settling tank, chemical reactor, demineralisation unit were made to measure conductivity, COD, pH, etc. The results are shown in Table 2. For evaluation, the discharge standards of metal industry wastewater to the receiving environment specified in the Water Pollution Control Regulation are taken as a basis [29].

Since the high conductivity creates a stain on the metal surface, it is necessary to reduce the conductivity for reuse. In the metal sector, the conductivity must be <30 so that there is no problem in the surface area of the metal [30]. It is seen that the conductivity after demineralisation is below 30 in Facility-A (Table 2). As the demineralisation method is both economical and reduces conductivity efficiently, it is efficiently used in Facility-A.

In Facility-B, three 2-hour composite influent water samples (Sample 1, 2 and 3) and an effluent sample from chemical wastewater treatment (Sample 4) were collected for the analyses to determine conductivity, pH, COD, TSS, etc. The results are given in Table 3.

As is seen in Table 3 while the pH (4.08 and 3.62, respectively) obtained for Sample 1 and 3 is below the discharge limits (6–9) and shows acidic characteristics, Sample 2 is basic with a pH value of 12.19 and exceeds the upper limit of discharge. Table 3 also shows that TSS in Sample 1, 2 and 3 (4886, 5270 and 5716 mg/L respectively) is quite high in comparison with discharge limits specified in the regulation [29]. Importantly, the COD value of Sample 4 (114 mg/L) does not fall into the range of the discharge limits [29]. In this case, efficient reduction of COD in wastewater treatment could be provided by the application of microalgae [31].

There are also different methods which are particularly based on membrane technology for the elimination of heavy metals from wastewater discharged from aluminium industry. For instance, it was found that commercial membranes could reduce conductivity in the anodising baths significantly [32]. Accordingly, the application of the membrane crystallisation technique to wastewaters discharged from an anodising industry in Denmark provided more than 80% fresh water from the wastewater [33].

In another wastewater characterisation study, membrane experiments were carried out with ultrafiltration, nano-filtration, and reverse osmosis membranes for the aluminium anodic oxidation wastewater discharged from a manufacturing facility in Kayseri, Türkiye [34]. The wastewater from this facility show very low pH and high aluminium content. It was determined that the water treated by both nano-filtration and reverse osmosis could be reused in the process. This provides economical profits as well as environmental benefits.

CONCLUSION

Methods such as supplying water to be used in such facilities in Türkiye from nearby wells reduce the cost of water. The low cost of water and difficulties of establishing water recovery systems could cause stakeholders from various industries not to deal with the issues of wastewater recycling. The high operating and investment costs of wastewater recovery systems and the doubts about their efficiency make these systems not very common. In addition, since the establishment of these recovery systems is not a legal requirement, facilities tend to supply well water for their processes. However, the rapid depletion of clean water resources and the necessity of going deep for the water to be drawn from wells could make wastewater recovery a great necessity soon.

In this study, the analyses were carried out to determine characteristics of wastewater discharged from Facility-A and Facility-B which produce stainless steel kitchenware and make anodising from secondary aluminium. The wastewater discharged from these two different aluminium facilities was characterised by using the parameters such as conductivity, pH, COD, TSS, etc. It was seen that the conductivity after demineralisation process in Facility-A is below 30, which proved that demineralisation method is effectively used in this facility to reduce conductivity efficiently. In Facility-B, while the pH obtained from influent water samples (Sample 1 and 3) is below the discharge limits and shows acidic characteristics, Sample 2 is basic and exceeds the upper limit of discharge [29]. It was also seen that the TSS of influent water samples is quite high in comparison with discharge limits specified in the regulation [29].

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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