FAILURE ANALYSIS OF BOTTOM PLATE OF POTABLE WATER TANK, PH-II, MEDINA-YANBU PLANTS[1]

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INTRODUCTION

The Plant Manager, SWCC Medina-Yanbu Plants in his letter No. SWCC/MY/2220/0182 dated June 15, 2005 addressed to the Manager, R&D Center, Al-Jubail informed about the holes and deep pitting in the bottom plate of Phase-II potable water tank No. 2 [01-TK-002]. The former requested the R&D Center for a detailed failure analysis and corrosion study and to provide suitable recommendations. A sample of the bottom plate was also received along with the letter.

BACKGROUND

The potable water tank No. 2 at PS-I in SWCC Medina-Yanbu plants, is in service since July 1998. There are four other identical potable water tanks at PS-I. Potable water from Phase-II and RO plant is stored in these tanks and pumped to Al-Madina Al-Munawarah. The inner side of the bottom plate which is in direct contact with water has a coating of Hempadur multi-strength 3553 whereas the external surface is in contact with a layer of asphaltic material. The tank is protected cathodically (impressed current) from internal as well as external side. Each tank is designed with separate cathodic protection system. Recently, the tank was opened for the first time for internal inspection. Some paint blisters and rust spots were observed on the bottom plate and 1st to 3rd course shell plate from the bottom. As a remedial measure it was decided to sand blast and repaint the bottom plate and 1st course shell plates completely. However, during the sand blasting holes and deep pitting were observed on the bottom plate.

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The research personnel from the Corrosion Department of SWCC R&D Center, Al-Jubail visited the failure site on Sept. 21, 2004. The relevant information about the tank failure was obtained from the concerned plant authorities; this was followed by a thorough physical inspection of the failed tank and the surroundings. At the time of visit the bottom plate was completely sand blasted and a primer coat was found applied over it. The selected portions of the failed bottom plate were also photographed. The plant authorities were requested to provide additional sample of failed bottom plate and other information relevant to failure investigation, which was received vide letter No. SWCC/MY/2220/0383 dated October 19, 2004. Table 1 describes the details of the tank.

VISUAL EXAMINATION

Figures 1 to 3 show two samples of bottom plate in the as received condition. A visual examination of the inner surface (water side) of the plate, cut from a location near the annular plate, showed holes and deep pits of varying depth (Fig. 1). The external surface (soil or underside) of the plate was found to be heavily corroded (Fig. 2). Figure 3 shows the bottom plate sample cut from a location away from the annular plate. Initiation and propagation of pits from water side can be seen. However, the external surface of bottom plate sample does not show any corrosion. A detailed inspection of the bottom plate revealed that pits and holes were confined within 1 meter area of the junction of annular and bottom plate and mainly concentrated over and/or near weld junction of two bottom plates. The bottom plate of the tank facing the neighboring tanks (south-east and south-west) was found to be more affected. A gap between the two overlapping section of bottom plates was also noticed. At certain locations some gap between soil surface and the bottom plate was also visualized.

ANALYSIS OF CORROSION PRODUCTS

The EDX studies of the corrosion products on the surface of the pits and a location away from the pits show the presence of significant concentration of chloride even after sand blasting (Figs. 4 and 5). The EDX concentration profiles of the corroded external surface and corrosion flakes obtained from the soil side of the bottom plate show strong peaks of Fe and O with other impurities in small concentration (Figs. 6 and 7). The

EDX concentration profile of calcareous deposit collected from the internal surface of the plate shows the presence of mainly Ca and O (Fig. 8).

DISCUSSION

The tank bottom plate is in contact with two different corroding environments i.e. potable water on the inner side and soil on the outer side. The inner surface is protected against corrosion by a combination of epoxy coating and cathodic protection whereas the outer surface is protected by a layer of asphalt and cathodic protection system. A study of samples of the failed bottom plate and MFL inspection report revealed that some areas of the plate experienced severe underside corrosion with little or no corrosion on the water side whereas certain areas showed initiation and propagation of pits from the water side with little under side corrosion. This indicates the possibility of initiation of corrosion simultaneously from both the sides with varying degree.

Considering the corrosion on the inner side (water side) of the plate, the holes and deep pits are caused due to the failure of epoxy coating applied over the inner surface of the bottom plate of the water tank. In the absence of the detailed examination of the failed coating and analysis of the cathodic deposits in the pits and blisters it is difficult to ascertain the actual cause of the coating failure at this stage of the investigation. However, the probable causes of the coating failure can be predicted. Coating and cathodic protection are both engineering disciplines with the primary purpose of mitigating and preventing corrosion. To obtain maximum corrosion resistance from the combination of a coating and cathodic protection, a number of factors, which have a basic influence on their combined effectiveness, must be taken into consideration. Any coating lacking resistance to alkalies, electroendosmosis, proper adhesion and optimum coating thickness is likely to fail by blistering under cathodic protection. The results of both laboratory testing and actual use of the combined system has shown that coating thickness and cathodic protection potential (CPP) are of real importance where a coating is to be used with cathodic protection [1]. The cathodic disbonding tests results have indicated that, in general, thicker coatings show better results. An increase in the value of CPP from – 850 mV vs $Cu/CuSO_4$ reference cell resulted in early blistering [2]. In another experiment, it has been shown that disbonding increased almost ten fold as the coating thickness decreased from the 65 mils range to 20 mils range [3].

Considering the present failure of the epoxy coating, the blistering in the coating may be due to the lack of any of the essential coating properties mentioned above. However, a definite pattern of the failure gives some speculation about the possible role of internal cathodic protection system in the blistering of the coating. An examination of the total applied cathbodic current and the distribution of cathodic current to different anodes over a period of time indicate some mal-functioning in the internal cathbodic protection system. However, to reach at a definite conclusion an expert evaluation of cathodic protection system is required. The blistering in the coating led to the formation of a number of electrolytic cell on the surface of the bottom plate. The anode of this cell consisted of the minute exposed area of the metal, and the cathode was the large coated area. The large potential difference of this passive-active cell accounted for the rapid corrosion at the small anode. This caused the formation of pits. The coating surrounding the anode and the activating property of corrosion products within the pits accounted for the tendency of corrosion to penetrate the metal rather than spread along the surface, this finally led to the formation of pits of varying depths to through holes. The presence of significant concentration of chloride in the pits even after sand blasting clearly shows its role in accelerating the corrosion at the bottom plate.

Considering the corrosion on the external side (underside) of the plate, the floor scanning report indicated heavy underside corrosion of the plates facing the neighboring tanks. The severity of underside corrosion is directly related to the corrosivity of the soil which depends upon a number of soil parameters e.g., pH; resistivity; redox potential; and moisture, sulfides, sulfates, and chlorides contents. However, the stray direct current (DC) or induced alternating current (AC) sources can also accelerate soil corrosion. Since the neighboring tanks have separate external impressed current cathodic protection systems, the possibility of stray DC effect in initiating and accelerating the underside corrosion can not be ruled out. Further, as a result of through holes in the bottom plate the high conductivity water came in contact with underside of the plate and caused heavy damaged over a period of time. The values of current densities and cathodic protection potentials for the external cathodic protection are calculated and listed in Table 2 and 3, respectively. The values of the current densities are higher than the typical current density required for the protection of buried underground steel structures [4]. This is a clear indication of some serious corrosion activity undergoing on the underside of the bottom plate which resulted in an increased demand for the cathodic current.

CONCLUSIONS

1. The corrosion of the bottom plate initiated simultaneously from the water side as well as soil side.
2. The water side corrosion initiated as a result of the blistering in the coating which led to localized attack and resulted in the pitting and holes. The blistering in the coating may be due to malfunctioning of internal cathodic protection system.
3. The heavy underside (soil side) corrosion is initiated possibly due to stray DC from the impressed cathodic protection systems operating on the other tanks in the vicinity. The contact of leaked potable water, through holes, with underside of the plate further contributed in accelerating the underside corrosion.

RECOMMENDATIONS

1. The expert evaluation of cathodic protection systems (both internal and external) of the failed tank as well as the neighboring tanks is needed in order to establish the role of CP in the failure.
2. An integrated external cathodic protection system for all the tanks will avoid the possible effect of stray direct current.
3. Standard coating application procedure recommended for the water tank bottom plate should be strictly followed.

REFERENCES

1. Munger, C.G., (1984), Corrosion prevention by protective coatings, National Association of Corrosion Engineers, Chapter-13, Coatings and Cathodic Protection, p.325.
2. Simpson, D.V.P. and Robinson, R.C., (1980), Experimental studies relate to effect of cathodic protection with certain generic coating systems, Presented at the 12th Annual Offshore Technology Conference, May.
3. Alexander, Stephen, H., (1969), Variables which influence cathodic disbonding test results, NACE, 25th Annual Conference, Preprint No. 13, NACE, Houston, TX.
4. ASM Metals Handbook, 9th Edition, Vol. 1, Properties and Selection: Iron and Steel, (1978): p.758.

Table 1. Information data about the potable water tank No. 2 [01-TK-002]

Diameter	96800 mm
Height	20000 mm
Design code	API 650 9th Edition 1993 – Appendix E
Capacity	140000 m^3
Product	Potable water
Product specific gravity	1.00
Maximum operating temperature	70^{o}C
Minimum design metal temperature	0^{o}C
Design pressure	Atmospheric
Design vacuum	Atmospheric
Corrosion allowances	
Shell	0 mm
Bottom plates	0 mm
Roof plates	0 mm
Roof framing	0 mm
Wind design per API 650	162 Km/h
Materials	
Shell rings 1 to 7	A 537 class 2
Annular plates	A 283-C
Roof plates	A 283-C
Columns	A312-TP 316L or equivalent
Structurals - external	A 36
Structurals – internal	A 479-316L or equivalent
Piping – external	A 106-B or m/f A 537 class 2
Piping - internal	A312-TP 316L or equivalent
Annular plate thickness	16 mm
Bottom plate thickness	6.35 mm (lap welded bottom)
Type of cathodic protection	Impressed current (external & internal)
Bottom top side (work side) paint dry film thickness (DFT):	
Primer	Hempadur 1559, DFT 40 µm
Second coat	Hempadur 3553 (light gray), DFT 200 µm
Top coat	Hempadur 3553 (off white), DFT 200 µm

Table 2. The applied current densities values for external cathodic protection

Date	Current Density (mA/m^2)
28/10/2003	3.94
29/11/2003	4.08
10/1/2004	5.03
4/2/2004	3.81
1/3/2004	4.08
29/3/2004	3.81

Table 3. The measured potential values for external cathodic protection (Cu-$CuSO_4$ Saturated)

Date	R1	R2	R3	R4	R5	R6	R7	R8	R9
28/10/2003	-914	-1019.5	-1173.4	-1016.4	-1108.5	-1160	-1250.2	-937.3	-1211.3
29/11/2003	-917.3	-1031.4	-1163.4	-1039.4	-1096.5	-1123	-1226.3	-945.1	-1197.9
10/01/2004	-917.3	-1030.4	-1163.3	-1058	-1094.5	-1121.8	-1226.3	-945.1	-1197.8
04/02/2004	-1240.6	-1077.8	-966.4	-1127.6	-1128	-1227	-873.6	-1161.5	-907.6
01/03/2004	-914	-1118.2	-1214	-1120.9	-1173.4	-1131.7	-1312.7	-981.4	-1277.1
29/03/2004	-964.4	-797	-1146	-1059.5	-1222.7	-937.6	-1264.4	-938.5	-922.2

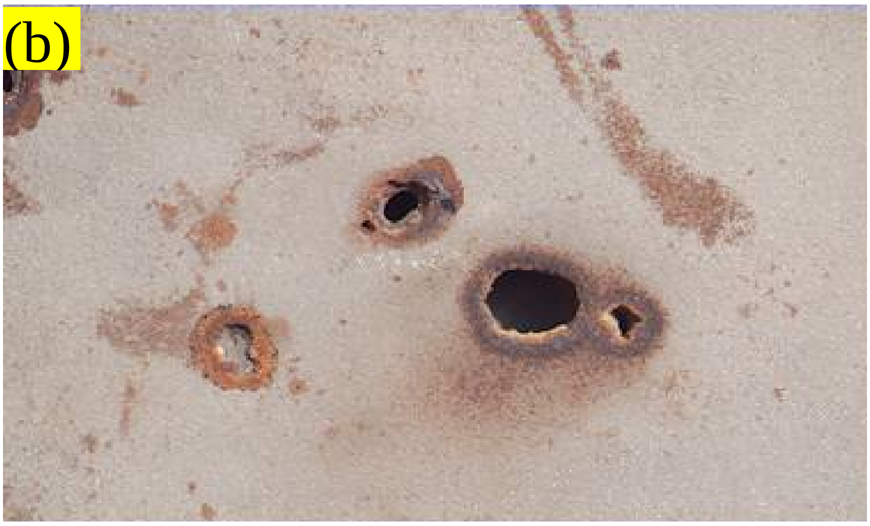

Figure 1a. Inner surface of the bottom plate, cut from a location near the annular plate, in the as received condition b. A close-up view of the hole and pit

Figure 2a. External surface (under side) of the bottom plate in the as received condition
b. A close-up view showing heavy corrosion

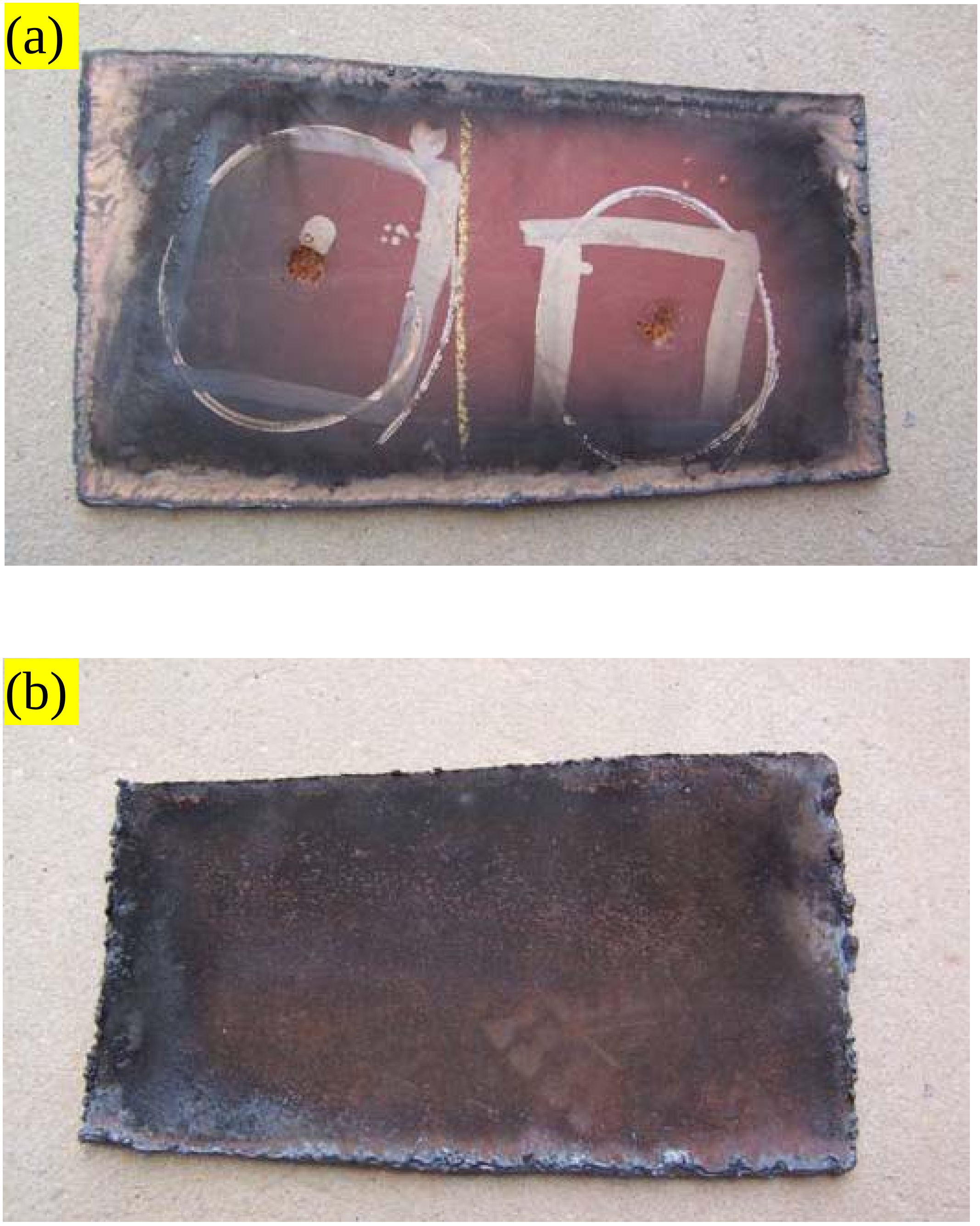

Figure 3(a). Inner surface of the bottom plate cut from a location away from annular plate showing only pits
(b) External surface (underside) of the bottom plate showing no corrosion

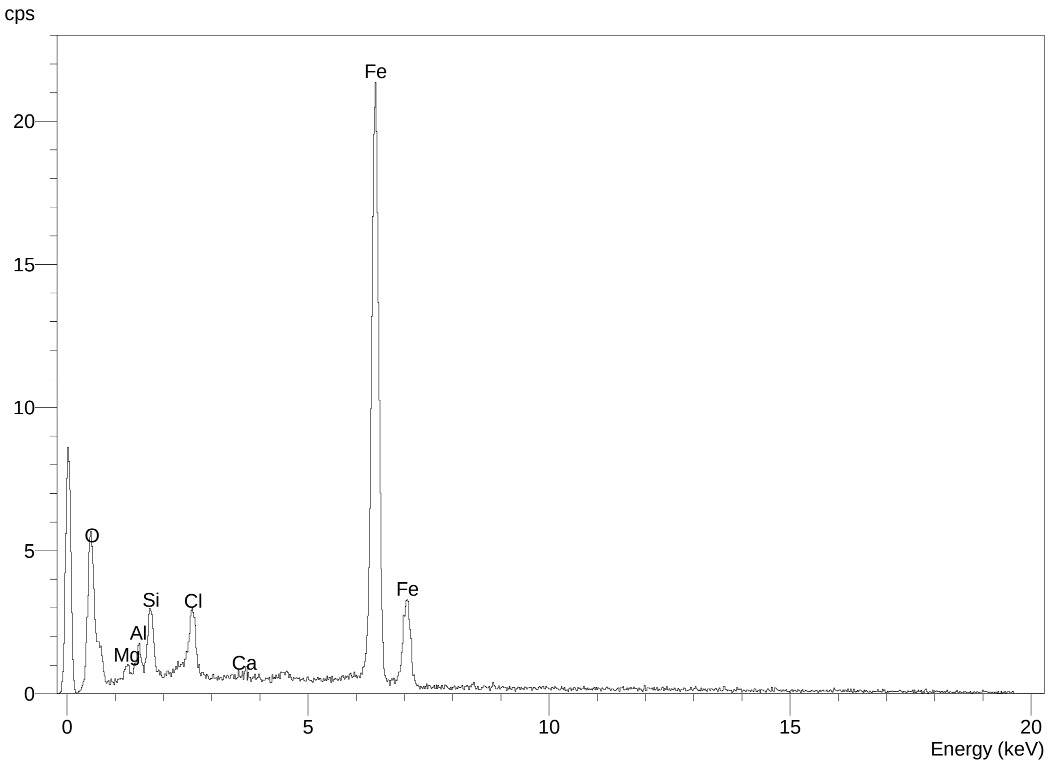

Figure 4. EDX profile of the corrosion products on the surface of the pit

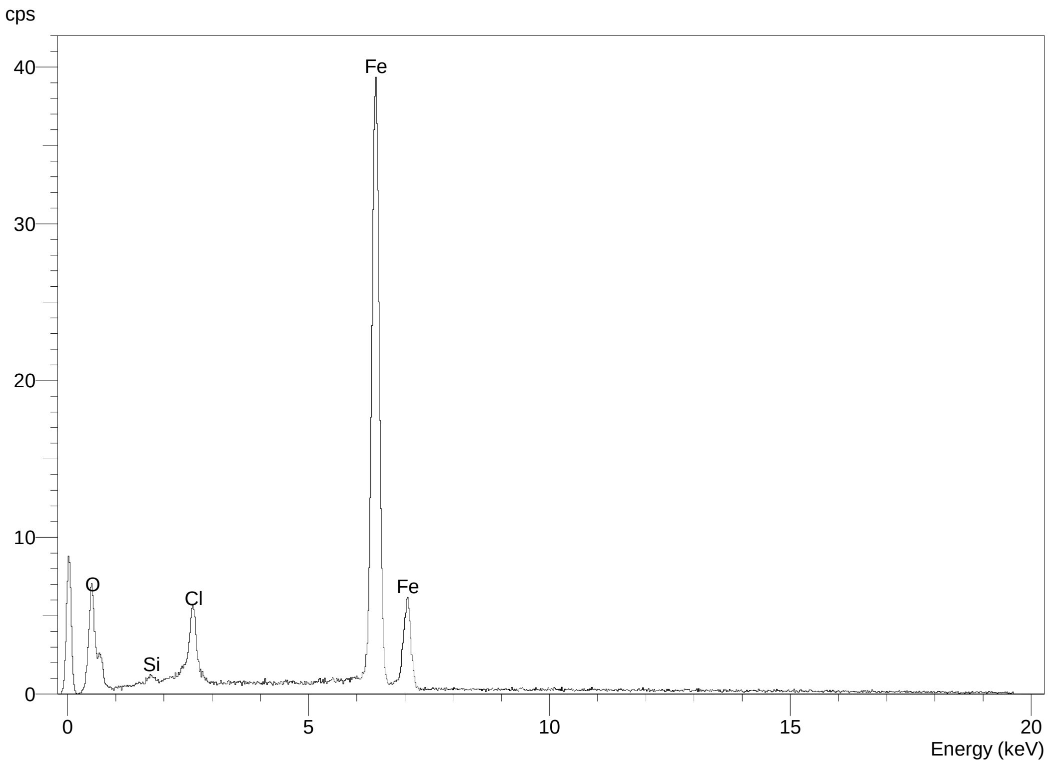

Figure 5. EDX profile of the corrosion products at a location away from the pit

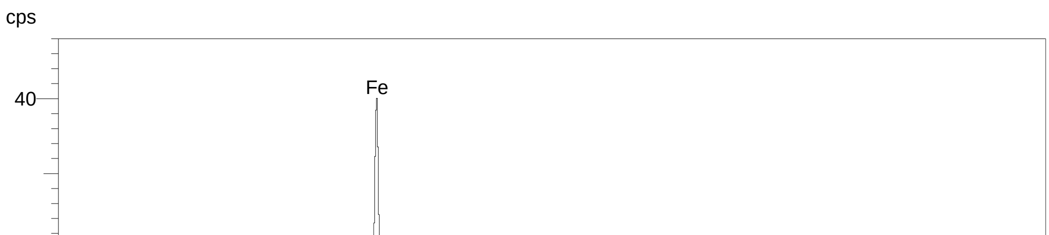

Figure 6. **EDX profile of the heavily corroded external surface of the bottom plate having deep pit and holes**

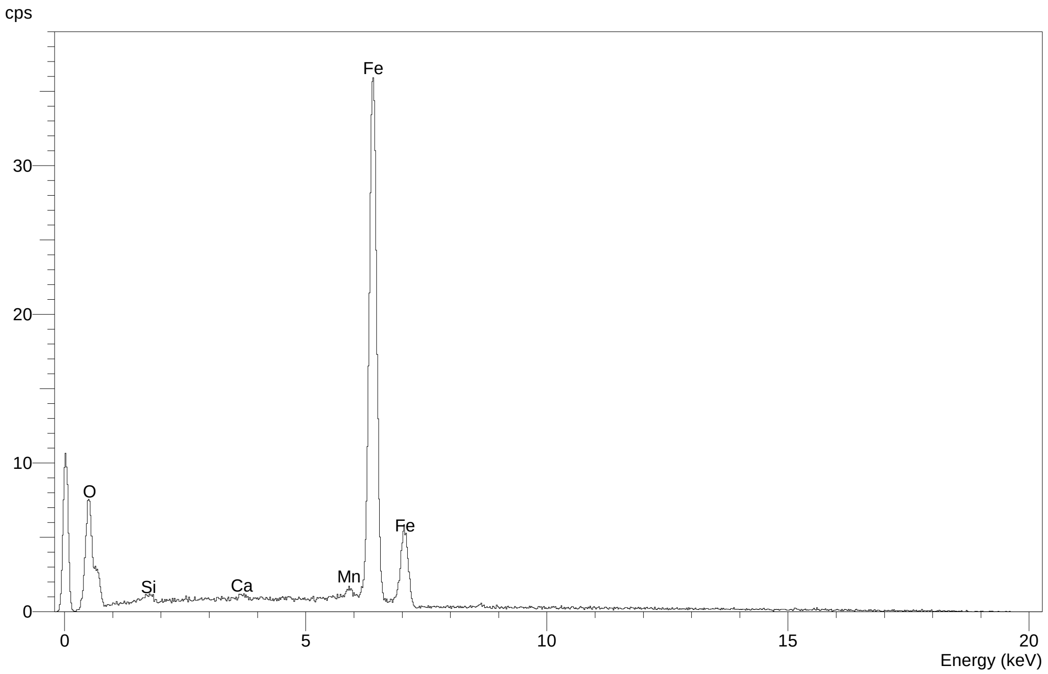

Figure 7. **EDX profile of the corrosion flakes obtained from external side of the bottom plate having holes**

Figure 8. EDX profile of calcareous deposit present on the inner surface of the bottom plate