I J A B E R, Vol. 14, No. 7, (2016): 5169-5180

COST OF CORROSION PROTECTION IN INDIAN OIL & PETROLEUM PRODUCTS TRANSMISSION PIPELINES – A CASE STUDY

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Abstract: *Pipelines are invariably used for transporting oil and petroleum products. Internal and external corrosion can be a major problem for such pipelines. The oil & petroleum products transmission sector makes a significant investment to control corrosion and protect these pipelines. In-situ corrosion auditing has been carried out for a 14 km long oil and petroleum products carrier pipeline in India and the findings are reported here. By using the Present Value (PV) method, the cost of protection was estimated to be US$1,137.05 per annum. By direct extrapolation of this value to the entire pipelines in India, annual cost of corrosion prevention was calculated to be US$1.685 million.*

Keywords: *corrosion auditing, cost of corrosion, cathodic protection, pipeline corrosion*

INTRODUCTION

Stirling (1945) estimated the annual loss due to corrosion as related to underground pipelines for USA to be US$50 million. He further showed through specific case studies that by application of suitable wrapping to the pipelines, a considerable amount could have been saved. Anderson (1947) presented a paper entitled "Our Billion-Dollar Side Show" in the annual meeting of NACE held at Chicago. According to Bureau of Standards Circular C-450, the annual cost of pipeline replacement due to corrosion was approximately US$200 million per year. Unruh (1951) reported that for one oil company, corrosion was costing US$1.5 million per year on a large pipeline system prior to the installation of sacrificial magnesium anodes. Following the installation of cathodic protection, the expenditure on corrosion damage was drastically reduced. Talley (1965), who also considered control of pipeline corrosion showed that cathodic protection of pipelines could lead to net annual savings of US$1.1million. Peabody (1967) in Chapter 16 of his book "Control of Pipelines Corrosion" published by NACE during 1967 discussed the economics of controlling corrosion of pipelines through cathodic protection by sample comparison between impressed current and sacrificial anode system.

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He also showed that if the pipeline sustained leakage due to inadequate maintenance the operator is confronted with the following indirect losses:

(i) The average cost of making a leak repair on the pipeline understudy

(ii) An average cost for property damage associated with a simple corrosion leak repair.

(iii) The value of product lost through the average corrosion leak.

(iv) Miscellaneous associated and consequential costs, such as insurance, good will etc.,

During 1991-2001, Koch et al (2001) conducted the systematic study on behalf of the Federal Highway Administration [FHWA] and NACE International. In this study, the total direct cost of corrosion for Gas and Liquid Transmission Pipelines in the USA was estimated to be US$7 billion. In 2004, US Department of Transportation presented a detailed report on the cost of repairs to USA onshore pipelines (2004). In that report, the cost of repairs to non-leaking gas pipelines was shown as US $ 20,000 – 40,000 million. Repairs to leaking pipelines was presented as approximately US$200,000 – 400,000 million, According to an estimate by speakers at a symposium on the corrosion of buried metals held at London, (1952) the annual cost of replacing corroded underground pipelines in Britain was of the order of £130million. According to an article on "the cost of corrosion" published in the Journal (Corrosion Prevention & Control) the annual cost of corrosion in the UK was £ 200 million during 1954. Of thisexpenditure, least £5 million was spent on the replacement of corroded buried pipelines. In Japan, Tanaka (1956) made an estimate of corrosion losses to underground cables and pipelines based on the number of failures per year caused by chemical and electrolytic corrosion, annual expenditure necessary for replacements and repairs, average repair expenditure per failure etc. The annual loss was shown as 74 billion Yen.

In India, pipelines are invariably used for transporting oil and gas. During 2015, the total network of crude oil, petroleum product and LPG pipeline in India was 23,067 km. Of this, the crude oil pipeline network was 9,537 km, the petroleum products pipeline network was 11,218 km and the LPG pipeline network was 2,312 km as reported by the India Brand Equity Foundation, India (2015).

Corrosion is one of the major problems of underground pipelines. It may occur either internally or externally. Internal corrosion depends upon the nature of any corrosive product transported through pipeline, along with its transport velocity. External corrosion is due to the heterogeneous nature of soils and local damage to external coatings on the pipelines. Every year, this industrial sector expends significant resources to protect their structures. Therefore it wasof interest to carry out a systematic corrosion auditon oil and gas transmission pipelines by the collection and analysisof data pertaining to control corrosion expenditure. The Present Value method was adopted to estimate the cost of corrosion.

SURVEY DETAILS

A survey was carried out on a 14 km long pipeline route of a major oil company at Chennai. Field data collected for carrier pipelines under road crossings was taken for this study. There were 7 different sizes of pipelines carrying different products, operating between Chennai Petrochemical Corporation Limited (CPCL) and the Fore-Shore Terminal (FST) at Chennai Port Trust, Chennai. The details of the pipelines were as follows:

1. 0.508m dia pipeline carrying white oil
2. 0.356m dia pipeline carrying black oil
3. 0.356m dia pipeline carrying white oil
4. 0.305m dia pipeline carrying lube oil
5. 0.457m dia pipeline carrying Naptha
6. 0.305m dia pipeline carrying motor sprit
7. 0.254m dia pipeline carrying aviation turbine fuel

The pipelines crossed the road at many places between CPCL and FST. The details are shown in Table 1.

SELECTION OF PROTECTION SYSTEM

Of the 14 km network length of pipelines, only 1.9 km length of pipelines crossed the road at different places through underground, culvert and hume pipe. Due to environment differentials, external corrosion can occur at such locations and hence those sections need to be protected. Cathodic protection in conjunction with protective coatings is the best method for protecting these assets. However, the application of protective coating is not possible because the pipelines were already laid in the soil. Cathodic protection is an alternative method of protection. In cathodic protection, an impressed current system could constitute a fire hazard. In order to avoid such a hazard, a sacrificial CP system had been selected for the structures. Details of the suggested sacrificial system were as follows:

- Zinc strip anodes for the carrier pipelines encased in the hume pipe as well as culvert
- Magnesium alloy anodes for the underground portion of the carrier pipelines.

(a) Calculation of cost of the cathodic protection system for the carrier pipelines encased in hume pipes as well as culvert.

Design parameters

Current density = $10 mA/m^2$

Design life = 20 years

Table 1
Details of Pipeline crossings between CPCL and FST

Location	*Pipeline diameter (m)*	*Length of crossings in meter*	*Type of crossings*
Thiruvorttiyur Road Crossings	0.305	20	Hume pipe
	0.457	20	
	0.254	20	
Manali Highway Crossings	0.305	15	Hume pipe
	0.356	15	
	0.356	15	
	0.508	15	
IOCL Inspection Road	0.254	6	Hume pipe
	0.457	6	
	0.305	6	
IOCL Inspection Road (Lube Line Diversion)	0.305	20	Underground
	0.305	8	Culvert
Concrete Pavement Road in front of	0.508	100	Underground
Tondiarpet Installation (Western Side)	0.356	100	
	0.356	100	
	0.305	100	
Tondiarpet Terminal (Southern side)	0.508	15	Underground
Road Crossings	0.356	15	Culvert
	0.356	15	
Eastern side of Tondiarpet terminal	0.457	20	Hume pipe
	0.457	360	Underground
Highway crossing (Opposite to Patel Nagar	0.356	15	Underground
water distribution station)	0.356	15	Hume pipe
Metro water road crossing	0.356	10	Culvert
	0.457	10	
	0.305	10	
Pipeline under culvert (opposite to diesel loco-shed)	0.508	15	Culvert
Diesel loco-shed crossing	0.356	8	Hume pipe
	0.356	8	
	0.457	8	
	0.305	8	
	0.305	8	
Karunanithi Road	0.508	15	Culvert
Highway crossing – near Tea Godown	0.508	40	Hume pipe
Pipeline under inspection road (Tea Godown)	0.356	10	Underground
	0.356	10	
	0.457	10	
	0.305	10	
	0.305	10	
	0.508	10	

contd. table 1

Location	*Pipeline diameter (m)*	*Length of crossings in meter*	*Type of crossings*
Below Tondiarpet Railway bridge	0.356	120	Underground
	0.356	120	
	0.457	120	
	0.508	120	
	0.305	120	
KOKG Yard Crossings – 1	0.356	15	Culvert
	0.356	15	
KOKG Yard Crossings – 2	0.457	6	Culvert
	0.508	6	
	0.305	6	
KOKG Yard Crossings – 3	0.457	10	Underground
	0.508	10	
	0.305	10	
Total length of the pipeline in meter		1899	

Coating efficiency	=	50% (assumed)
Type of anode	=	Zinc Strip Anode
Anode capacity	=	770 Ah/kg
Anode Utilization Factor	=	0.8 (80%)
Size of the anode	=	45 mm x 45mm x 1500mm with 1 meter long of 16 sq.mm copper
Weight of anode	=	22 kg.

Cost Details

The supply cost per zinc strip anode was US$190.48 and the installation cost per anode was US$126.98. The pipe-to-cable cathode connection was achieved using a EUTECTIC WELD with epoxy encapsulation for was US$134.92 per location and earth work excavations for cable laying at a depth of 1.5 meterbelow the ground level was US$4.37 per running meter.

Calculation for determination of weight and size of zinc strip anodes

Methodology involved to determine the weight of zinc strip anode required to protect the carrier pipelines encased in hume pipe as well as in the culvert is shown in Table 2.

No. of zinc strip anode required = 49

Total number of locations = 14

Table 2
Determination of weight of anodes required for protecting pipelines encased in hume pipe as well as culvert

Pipeline dia(m)	*Length of crossing (m)*	*Π*	*Surface area of the pipeline (m^2) [a x b x c]*	*Coating Efficiency*	*Current density (mA/m^2)*	*Current requirement (A) [d x e x f)*	*Hours of protection (Year x day x hours)*	*Anode capacity x Utilization factor (Ah/kg)*	*Weight of anode required (kg) (g x h / i)*	*Weight of Commercial Available anode (kg)*	*No. of anode required*
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*	*(j)*	*(k)*	*(m)*
0.305	20	3.14	19.15	0.5	10	0.095	175200	616	27.019	22	2
0.457	20	3.14	28.69	0.5	10	0.143	175200	616	40.671	22	2
0.254	20	3.14	15.95	0.5	10	0.079	175200	616	22.468	22	2
0.305	15	3.14	14.36	0.5	10	0.071	175200	616	20.193	22	1
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.508	15	3.14	23.92	0.5	10	0.119	175200	616	33.845	22	2
0.254	6	3.14	4.78	0.5	10	0.023	175200	616	6.541	22	1
0.457	6	3.14	8.6	0.5	10	0.043	175200	616	12.229	22	1
0.305	6	3.14	5.74	0.5	10	0.028	175200	616	7.963	22	1
0.305	8	3.14	7.66	0.5	10	0.038	175200	616	10.807	22	1
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.457	20	3.14	28.69	0.5	10	0.143	175200	616	40.671	22	2
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.356	10	3.14	11.17	0.5	10	0.055	175200	616	15.642	22	1
0.457	10	3.14	14.34	0.5	10	0.071	175200	616	20.193	22	1
0.305	10	3.14	9.57	0.5	10	0.047	175200	616	13.367	22	1
0.508	15	3.14	23.92	0.5	10	0.119	175200	616	33.845	22	2

contd. table 2

(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*	*(j)*	*(k)*	*(m)*
0.356	8	3.14	8.94	0.5	10	0.044	175200	616	12.514	22	1
0.356	8	3.14	8.94	0.5	10	0.044	175200	616	12.514	22	1
0.457	8	3.14	11.47	0.5	10	0.057	175200	616	16.211	22	1
0.305	8	3.14	7.66	0.5	10	0.038	175200	616	10.807	22	1
0.305	8	3.14	7.66	0.5	10	0.038	175200	616	10.807	22	1
0.508	15	3.14	23.92	0.5	10	0.119	175200	616	33.845	22	2
0.508	40	3.14	63.8	0.5	10	0.319	175200	616	90.728	22	5
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.356	15	3.14	16.76	0.5	10	0.083	175200	616	23.606	22	2
0.457	6	3.14	8.6	0.5	10	0.043	175200	616	12.229	22	1
0.508	6	3.14	9.57	0.5	10	0.047	175200	616	13.367	22	1
0.305	6	3.14	5.74	0.5	10	0.028	175200	616	7.963	22	1
	399										49

Total length of crossings (meter) = 399

Therefore total cost of the zinc anodes required for protection=

(No. of anodes required x Supply cost of one anode + Installation cost of one anode)

49 x (US$190.48 + US$126.98) = US$15,555.54

Pipe to cable connection for all the locations

(14 x US$134.92) = US$1,888.88

Earthwork excavation for cable laying

(399 x US$4.37) = US$1,743.63

Total cost of zinc strip anode for 20 years' service

(15,555.54 + 1,888.88 + 1,743.63) = **US$ 19,188.05**

(b) Calculation of cost of cathodic protection system for the carrier pipelines under road crossings.

Design parameters

Current density	=	10mA/m^2
Design life	=	20 years
Coating efficiency	=	50% (assumed)
Type of anode	=	Magnesium alloy anode
Anode capacity	=	1100 Ah/kg
Anode utilization factor	=	0.8 (80%)
Size of the anode	=	125mm dia x 1500 mm long
Weight of anode	=	22 kg.

Cost Details

The supply cost per magnesium alloy anode was US$285.71 and the installation cost per anode was US$126.98.The cost of the pipe-to-cable connection by EUTECTIC WELD with epoxy encapsulation for cathode connection was US $134.92 per location and earth work excavation for cable laying at a depth of 1.5 meter below the ground level was US$4.37 per running meter.

Calculation for determination of weight and size of magnesium alloy anodes

The methodology involved to determine the weight of magnesium alloy anodes required for protecting the underground portion of the carrier pipelines under road crossings is shown in Table 3.

Table 3
Determination of weight of anodes required for protecting pipelines buried underground in road crossings

Pipeline dia(m)	*Length of crossing (m)*	*Π*	*Surface area of the pipeline (m^2) [a x b x c]*	*Coating Efficiency*	*Current density (mA/m^2)*	*Current requirement (A) (d x e x f) /1000*	*Hours of protection (Year x day x hours)*	*Anode capacity x Utilization factor*	*Weight of anode required (g x h / i)*	*Weight of Commercial Available anode*	*No. of anode required*
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*	*(j)*	*(k)*	*(m)*
0.305	20	3.14	19.15	0.5	10	0.095	175200	880	18.913	22	1
0.508	100	3.14	159.51	0.5	10	0.797	175200	880	158.675	22	8
0.356	100	3.14	111.78	0.5	10	0.558	175200	880	111.092	22	6
0.356	100	3.14	111.78	0.5	10	0.558	175200	880	111.092	22	6
0.305	100	3.14	95.77	0.5	10	0.478	175200	880	95.165	22	5
0.508	15	3.14	23.92	0.5	10	0.119	175200	880	23.691	22	2
0.457	360	3.14	516.59	0.5	10	2.582	175200	880	514.052	22	24
0.356	15	3.14	16.76	0.5	10	0.083	175200	880	16.524	22	1
0.356	10	3.14	11.17	0.5	10	0.055	175200	880	10.95	22	1
0.356	10	3.14	11.17	0.5	10	0.055	175200	880	10.95	22	1
0.457	10	3.14	14.34	0.5	10	0.071	175200	880	14.135	22	1
0.305	10	3.14	9.57	0.5	10	0.047	175200	880	9.357	22	1
0.305	10	3.14	9.57	0.5	10	0.047	175200	880	9.357	22	1
0.508	10	3.14	15.95	0.5	10	0.079	175200	880	15.728	22	1
0.356	120	3.14	134.14	0.5	10	0.67	175200	880	133.39	22	7
0.356	120	3.14	134.14	0.5	10	0.67	175200	880	133.39	22	7
0.457	120	3.14	172.19	0.5	10	0.86	175200	880	171.218	22	8
0.508	120	3.14	191.41	0.5	10	0.957	175200	880	190.53	22	7
0.305	120	3.14	114.92	0.5	10	0.574	175200	880	114.278	22	1
0.457	10	3.14	14.34	0.5	10	0.071	175200	880	14.135	22	1
0.508	10	3.14	15.95	0.5	10	0.079	175200	880	15.728	22	1
0.305	10	3.14	9.57	0.5	10	0.047	175200	880	9.357	22	1
	399										49

No. of Magnesium Alloy anode required	=	92
Total number of locations	=	8
Total length of crossings (meter)	=	1500

Therefore, the total cost of anodes required for protection=

(No. of anode required x Supply cost of anode + Installation cost of anode)

92 x (US$285.71 + US$126.98)	=	US$37,967.48
Pipe-to-cable connections for all the locations		
(8 x US$134.92)	=	US$1,079.36
Earthwork excavations for cable laying		
(1500 x US$4.37)	=	US$6,555
Total cost of magnesium alloy anode for 20 years		
(US$37,967.48 + US$1,079.36 + US$6,555)	=	US$45,601.84

Determination of Annual Cost of Protection

As can be seen from the foregoingan Oil and Gas Pipeline operator normally would spendquite a considerable amount each year to mitigatecorrosion. Therefore,during the present study, the cost of corrosion was analyzed by considering the following:

- As per the Income Tax Act, Oil and Gas Pipeline industry has to pay 35% of the net income as tax (t). This factor has been taken into account while computing the cost of corrosion, since the amount spent on mitigation of corrosion is an expenditure.
- In order to determine the present value for the future expenditure on corrosion control programme, an interest rate (i) of 6.25% has also been considered

Data generated for cost of corrosion of cathodic protection by zinc strip anodes and magnesium anodes for the carrier pipelines are shown in Table 4. This table summarizes annual expenditure, present worth factor, tax credit, present value, annual cost factor and equivalent annual cost in that order.

The annual cost of cathodic protection for 1.9 km pipelines was estimated to beUS$1,137.05

Annual Cost of Sacrificial Cathodic Protection System for Carrier Pipeline in India

Assuming that the same environment is prevailing at all places; the annual cost of corrosion protection for entire carrier pipeline network in India was estimated. During 2012-13, the total network of carrier pipeline (crude oil and petroleum products) in India was 20,755 km.

Table 4
Equivalent annual cost of cathodic protection for carrier pipelines encased in hume pipe / culvert and buried underground

Expenditure details	*Period of occurrence*	*Amount (US $)*	*Present worth factor* $\frac{1}{(1+i)^n}$	*Tax credit (1-t)*	*Present value (US $)*	*Annual cost factor* $\frac{i \ x \ (1+i)^n}{(1+i)^n - 1}$	*Equivalent annual cost (US $)*
		(A)	*(B)*	*(C)*	*(D) [A X B X C]*	*(E)*	*(F) [D X E]*
Cathodic Protection using Zinc Strip Anode system	Once in 20 years	19,188.05	0.30	0.65	3,741.66	0.09	336.74
Cathodic Protection using Magnesium Alloy Anode system	Once in 20 years	45,601.84	0.30	0.65	8,892.35	0.09	800.31
Total Equivalent Annual Cost							1,137.05

Length of pipeline is to be protected

Out of 14 km of the example pipeline, only 1.9 km needed to be protected. A direct extrapolation of the same proportion to the entire pipeline network (20,755 km) carrying crude oil and petroleum products in India would work out as follows:

$$\frac{1.9}{14} \times 20,755 = 2,816.75 \; km.$$

Therefore, it can be estimated thata total length of 2,817 km of pipeline will need to be protected.

Cost of protection

The annual cost of corrosion protection for the 1.9 km worked out to be US$1,137.05/-. A direct extrapolation of the same expenditure to pipelines carrying crude oil and petroleum products (2,817 km length) in India worked out as follows:

$$\frac{1,137.05}{1.9} \times 2,817 = US\ \$\ 1,685,826.23$$

Or approximately US$1.685 million.

CONCLUSION

The annual cost of cathodic protection for 1.9 km length of a pipeline carrying crude oil and petroleum products was estimated to beUS$1,137.05/-. By direct extrapolation of the same to the entire pipelines in India, the annual cost of cathodic protection during the year 2014-15was worked out to beUS$1.685 million.

Acknowledgment

The authors sincerely thanks Mr.Ashok Mittal, Honorable Chancellor, Dr.Sanjay Modi, Executive Dean, Lovely Faculty of Business and Applied Arts, Dr. Suresh Kashyap, Head, School of Business and other dignitary members at Lovely Professional University, Phagwara, Punjab for their support and advice. The authors gratefully acknowledge the research project awarded to Dr. R. Bhaskaran by the Indian Council of Social Science Research, New Delhi. The cooperation obtained from Indian Oil Corporation Limited, Chennai is also gratefully acknowledged. The authors thank the faculties and other members in School of Business of Lovely Professional University for their kind encouragement in pursuing this study.

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