Evaluation Study of Discharge Gas Cooling Water System of Natural Gas Compressor Station

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Summary: Evaluation of discharge gas cooling system of a natural gas compressor station was studied. Scale deposition potential and corrosion forming tendencies of the cooling water were monitored. Plant operating at high Holding Time Index contributed towards increased scale forming potential of cooling water. Corrosion data analysis showed slightly high rate of corrosion of cooling water that may be due to improper management of acid dosing in the system. Absence of side stream filtration unit might have supported increased turbidity in the system that helped increased growth of microbial colonies in the water. Cooling water quality standards did not support in keeping balance between corrosive and scale forming potential of the circulating water. Therefore, improved limits of cooling water quality standards have been suggested in this work.

Introduction

Natural gas is a mixture of gaseous hydrocarbons, predominantly methane. The gas after exploration from a gas field is passed through purification operations and then supplied to the consumers through underground pipeline network. For regular transmission of the gas to the end-users, the pressure of the gas is maintained by compressor stations. The gas from (X) gas field is brought to the compressor station (A) where it is compressed from ~800 psi to the required pressure 1100 psi. Due to compression, temperature of the gas increases to about 185 °F. This high temperature gas has the potential to damage coating/ protective layers of the transmission pipeline. Cracks appear in the coating layer make pipeline susceptible against the attack of corrosion leading to the degradation of the pipeline material. To avoid this problem, cooling water system had been installed to bring down temperature of the compressed gas to the minimum required value around 110 °F.

An open re-circulating cooling water system with forced draught counter flow type cooling tower was installed at the compressor station (A) and had been in operation for the last 10 years. Problems encountered in cooling water systems are due to characteristics/ nature of the spent water [1, 2]. There are three problems, which are common to all cooling water systems. These are scaling/ deposition, corrosion and microbial growth. All the circulating waters in the cooling system contain some level of impurities that cause scaling and corrosion in heat exchanger and piping system. In cooling tower itself, combination of humid air and warm water provides an ideal environment for microbial growth. Treatment programs have been applied to all cooling water systems for many years [3]. These programs contain active components referred to as scale/ corrosion/ microbiological growth inhibitors. They serve to minimize performance problems and increase efficiency of the cooling water system. Control of the treatment program is important to ensure that desired amounts of actives are present in circulating water.

This study was conducted for the evaluation/ optimization of discharge gas cooling water system of a natural gas compressor station. Scope of the work was determined as; testing of source water and circulating water, measurement of corrosion and scale formation-its extent and rate, determination of efficiency of corrosion/ scale inhibitors and other additives, recommendations and suggestions for the improvement of performance of the existing system. One of the underlying objectives of the study was to work out that how the cooling water system could be run on optimized conditions to get the best possible results of the water treatment program.

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Results and Discussion

Measurement of Scale/ Deposition Potential

Cooling water treatment system, on the whole, was not operating at optimized conditions. Values of some water quality parameters showed variations from the recommended values (Table-1). Results of Water quality tests conducted at the Institute's laboratory were not in conformity with the tests being performed at the compressor station. Visual check of the heat exchanger through the inspection window revealed a moderate build up of scale on the tubes. A significant amount of corrosion products were evident in the heat exchanger and the tube bundle was nearly chocked with debris. Total hardness was found higher than the accepted values.

Increased level of hardness leads to the scaling potential and influences efficiency of the scale inhibitors. Calcium carbonate contributes major share to the scale build up in cooling water operations. Above a pH 8.2, bicarbonate ions dissociate to carbonate and got insoluble as temperature of the water increases. Moreover, high level of hardness also renders scale inhibitors ineffective. Rather than control of scale formation by inhibitor, the Ca-inhibition complex itself begins to precipitate and form a scale [4-5]. All such factors might have played a role in the development of scale during plant operations.

Cycles of Concentration (CoC)

Cycles of concentration of the cooling water were also evaluated by estimating concentration of chloride ions in make up water and in circulating water. CoCs were found higher than the recommended value (Table-1). CoC determines the water chemistry without chemical treatment. CoC increases amount of impurities in cooling water system. One of the main problems associated with high cycle operation is the increase in Holding Time Index (HTI), which is the time required to concentrate the make up solids by a factor 2. This is an important factor in setting control limits where chemical feed may be interrupted. It is also important for establishing an effective dosage for biological control agents, which are slug fed into the system [6]. The present system was operated at high HTI, *i.e.* at 62 hours. Most industrial cooling systems are operated at HTI 48 hours or less (Fig. 1). High value of system HTI contributed to longer period of stay of the contaminants in the system. This increased concentration of scalents raised the saturation ion

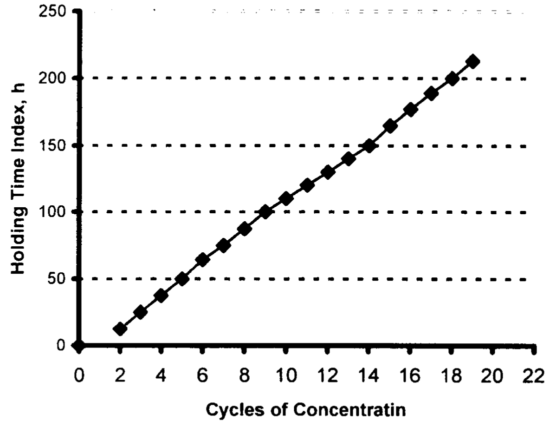

Fig. 1: Profile of cycles of concentration of cooling water regarding holding time index.

Table-1: Analysis of raw and treated water of Compressor Station A.

Parameter	Units	Raw Water	Cooling water 1st visit	2nd visit	3rd visit	Aveg.	*Rec.val.	Aspect
PH	-	7.9	7.6	7.7	8.1	7.8	7.8-8.3	OK
Conductivity	μS/ cm	682	1752	1982	1618	1784	1600	Higher
Total Dissolved Solids	mg/ L	450	1276	1335	1293	1301	1200	Higher
T. Hardness as $CaCO_3$	mg/ L	273	827	853	796	825	800	
Calcium as $CaCO_3$	mg/ L	160	403	391	345	379	380	-
Magnesium as $MgCO_3$	mg/ L	184	356	409	436	400	420	-
M-alkalinity as $CaCO_3$	mg/ L	167	176	220	341	245	350	-
P-alkalinity as $CaCO_3$	mg/ L	Nil	Nil	Nil	10	10	-	-
Bicarbonate as $CaCO_3$	mg/ L	201	71	81	78	76	-	-
Chloride as Cl^-	mg/ L	33	196	188	191	190	200	-
Sulphate as SO_4^{-2}	mg/ L	204	604	562	727	631	800	-
Sodium as Na^+	mg/ L	41	211	196	215	207	-	-
Potassium as K^+	mg/ L	4.6	34	58	63	51	-	-
Nitrite as NO_2^{-1}	mg/ L	Nil	Nil	Nil	Nil	-	-	-
Phosphate as PO_4^{-3}	mg/ L	-	6.31	7.1	6.4	6.6	2-5	Higher
Turbidity	NTU	3	21	24	19	21.3	-	-
Cycle of Concentration	-	-	5.9	5.7	5.8	5.8	2-4	Higher

*Values recommended by the chemical supplier.

factors of minerals, thereby increased severity of scale forming potential. This was also evident from the results of high value of hardness in the cooling water samples.

Langelier and Ryznar Stabiliy Index

Scale forming and/ or corrosive tendencies of the cooling water samples were also predicted by using Langelier Saturation Index (LSI) and Ryznar Stability Index (RSI). These two indices are commonly used in water treatment industry to evaluate nature of the water. In both cases, these indices are based upon a calculated pH of saturation (pHs) of calcium carbonate [7]. This pHs value is then used in conjunction with the water's actual pH to calculate value of the indices. Interpretation of the results of LSI and RSI are given in Table-2. Results of LSI showed slightly corrosion forming tendencies of the cooling water system as under.

LSI = pHa-pHs

Where;

pHs = pCa + palk + Cscale
pHa = actual pH of the sample
pHs = saturated pH
pCa = calcium hardness factor (expressed as ppm $CaCO_3$)
palk = M-alkalinity factor (expressed as ppm $CaCO_3$)
C = total solids (expressed as ppm at the temp. of sample)

Ca-hardness = 379 ppm
M-alkalinity = 245 ppm
TDS = 1301 ppm
Temperature = 66 °F

pCa = 2.95
palk = 2.54
Cscale = 2.38

pHs = 2.95 + 2.54 + 2.38 = 7.87
pHa = 7.80

LSI = pHa-pHs

LSI = 7.80-7.87 = -0.07 (Balanced but pitting corrosion potential, Table-2)

Table-2: Interpretation of LSI and RSI.

LSI	Tendency of Water
+2.0	Scale forming and noncorrosive
+0.5	Slightly scale forming and noncorrosive
0.0	Balanced but pitting corrosion potential
-0.5	Slightly corrosive and nonscale-forming
-2.0	Highly corrosive
RSI	Tendency of Water
< 4.0	Heavy scaling
5.0-6.0	Light scaling
6.0-7.0	Little scale or corrosion
7.0-7.5	Significant corrosion
7.5-9.0	Heavy corrosion
> 9.0	Corrosion intolerable

Since pHs > pHa, the water had corrosion forming tendencies. Also greater the deviation of actual pHa from pHs, the more pronounced would be instability. Ryznar Stability Index (RSI), a modified form of LSI, also showed light corrosion forming tendencies of the cooling water samples as follows.

RSI = 2 pHs-pH

RSI = 2 (7.87)-(7.8) = 7.9 (Significant corrosion forming tendency, Table-2)

In using RSI, a water is considered to be corrosive when the Stability Index exceeds approximately 6.0 and to be scale-forming when index is less than 6.0.

Measurement of Corrosion Rate

General corrosion rate was determined by installing corrosion coupons in circulating water. Results are tabulated in corrosion data analysis sheet (Table-3). Cooling water showed slightly high rate of corrosion. Although cooling water quality parameters tested in the laboratory were found within satisfactory limits, corrosion potential of the water, however, indicated that acid dosing might not be managed properly. A significant amount of local corrosion was observed on the shell side of the heat exchanger. Tube bundle of the heat exchanger was full of corrosion products and debris as seen from the inspection window. Rate of corrosion of the cooling water was calculated using following formula [8].

Table-3: Corrosion data analysis sheet.

Coupon	A	B	C
Material	Mild steel	Mild steel	Mild Steel
Date in	27-06-07	27-06-07	27-06-07
Date out	06-08-07	06-08-07	06-08-07
Exposure time, days	40	40	40
Initial weight, g	11.9606	11.9713	11.9361
Final weight, g	11.4230	11.3210	11.4973
Weight loss, g	0.5376	0.6503	0.4388
Corrosion pressure, mpy	12.61	15.26	10.30
Aspect	Not good	Not good	Not good
Deposits	Significant	Significant	Significant
Visual pitting	ND*	ND	ND

*Not detected

$$\text{mpy} = \frac{\text{WD x 143,700}}{\text{D x S x T}}$$

Where;

mpy = Corrosion pressure, mills per year
WD = Weight difference of corrosion coupon in grams
D = Density (carbon steel), 7.85 g/cm^3

S = Surface area of coupon, 19.5 cm^2
T = Number of days

Results in mpy are evaluated as follows:

mpy = < 1 very good protection
mpy = < 3 good protection
mpy = < 6 acceptable protection
mpy = $< 6\text{-}15$ results must be improved
mpy = > 20 not acceptable protection
mpy = > 40 very bad protection

Slime Deposition

Cooling water systems provide an ideal medium (32-38 °C temperature and 8-9 pH of water) for microbial growth. The water source contains all the naturally occurring organisms and nutrients along with air, heat and light that support microbial activity. The classes of microorganisms that proliferate in open re-circulating cooling water systems are algae, fungi and slime forming bacteria [9, 10].

Algae biomass was found attached to the cooling tower structural members and in the drift eliminator. Some algae were found deposited on the metal surface of pipes and valves. Due to presence of slime forming bacteria a combined biological-mineral bio-film was apparent on the tubes of heat exchanger. High turbidity was found there in the cooling water samples. Turbidity in cooling water works as supporting media for the growth of microorganism [11]. System should be equipped with a side stream filter to control suspended particulate matter and to minimize turbidity in the circulating water. Alternatively, a pump should be set up to remove sludge from cooling tower basin as per requirement. A periodic cleaning of the sludge from the bottom of the cooling tower will also help control microbial growth in the system. There should be no visible sign of algae or other biomass inside the cooling tower.

Experimental

Study was scheduled to complete within the contract period of six months. The work was designed on the basis of visual inspection of the cooling water system, sampling of raw and circulated water, collection of samples of scale/ deposits and corrosion products, installation of corrosion coupons, water treatment tests/ analysis, compilation of results and finalization of the report. Work plan was divided into three stages. At first stage, a thorough understanding of the actual problems of cooling water facility was developed by visual inspection of the compressor station. A detailed discussion with the concerned staff members of the compressor station pertaining to the cooling water problems and working efficiency of the plant was made. Six sampling points of circulating water were established as; (i) raw water from storage tank (ii) sump water from cooling tower (iii) inlet of the heat exchanger (iv) outlet of the heat exchanger (v) cooling tower channel (vi) and source water. To get consistency of the results, samples had been collected from the same established sampling points throughout the study period.

At second stage, a thorough visual inspection of the cooling water pipelines (internal and external sides) system was conducted. Conditions of valves/ joints, piping equipment and cooling tower structure were also examined. Samples of scale/ deposition and corrosion products were taken from heat exchanger tubes (shell side) and from cooling water pipelines. Water treatment tests performed at the compressor station by the present staff were inquired. Water testing facilities available at the compressor station were also inspected. Necessary information related to water treatment chemicals/ additives, their dosages and modes of application were discussed. Second time sampling of the cooling water was also conducted.

At third stage, corrosion coupons were installed in circulating water and they were removed after 40 days of exposure time. The coupons were brought to the Institute's laboratory for examination and subsequent estimation of the corrosion potential of cooling water.

Water treatment tests were conducted at Environmental Engineering Laboratory, of the Institute. All the water treatment quality parameters were tested following procedures adopted from Standard Methods for the Examination of Water and Wastewater [12]. Reagent kits used were made of HACH Company, USA. Photometric analyses were done by Spectrophotometer (DR/ 2010), HACH, USA [13]. Conductivity, total dissolved solids (TDS) and pH were measured by portable multiparameter (Sension156), HACH, USA. Cycles of concentration were calculated by dividing amount of chloride ions in circulating water by the amount of chloride ions in make up water. Mild steel corrosion coupons were purchased from the same company of USA. Coupons were mounted in a coupon handling assembly made of special PVC material. Coupons were installed at the exit of the heat exchanger where conditions due to highest temperature were the most critical. Installation of the corrosion coupon followed consideration of the four key factors [14]: placement of the coupons, orientation of the coupon in the flow of water, interval of exposure time, and the flow velocity across the coupons. Flow rate of the cooling water in coupon assembly was fixed at 8 L/ min. Coupons were attached in the assembly with plastic holders and they remained completely submersed in the water throughout the exposure time. Coupon assembly remained under continuous supervision of the staff of the compressor station so that a regular flow of circulating water could be maintained in the assembly during the period of experimental set up. Microbial contamination in cooling water was determined by Membrane Filtration Method using pre-poured agar plate technique and numbers of colonies per 100 mL were calculated.

Conclusions

Evaluation study of discharge gas cooling system concluded that cooling water quality standards did not support in keeping balance between corrosive and scale forming potential of the circulating water. Since LSI and RSI of the circulating water suggested that the water is basically corrosive in nature, particularly at elevated cycle of concentration, therefore, improved limits of cooling water quality standards have been suggested in this report, which would help modify water treatment program. To get the best possible results of the water treatment program, cooling water system is suggested to optimize on the conditions; pH = 7.5-7.8, alkalinity = 60-100, phosphate (PO_4^{-3}) = 2-4. Plant should preferably be run at a minimum number of Cycles of Concentration (CoC = 3-5). Since heat exchanger tubes are chocked with corrosion products, debris and scaling, water jet cleaning followed by acid cleaning with 5-7 % HCl along with 0.1 % corrosion inhibitor is strongly recommended. System should be equipped with a side stream filtration unit to control suspended particulate matter and to minimize the colloidal matter into the cooling water. The side stream filter should be designed for a flow of about 2 % of the recirculation rate so that entire volume of the system water is filtered every 48 hours. An effective control on microbial growth can be obtained by adopting continues maintenance dose of Free Chlorine Residual of 0.5-1.0 ppm in circulating water.

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