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A Review of Applied Modern Condition Monitoring and Best Maintenance Engineering Practices in Reciprocating Gas Compression Plants

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Abstract:

The gas compression plant is one of the major unit in gas industries. Gas needs to be compressed either for process handling, power generation, gas injection or transferring either treated or raw gas as products. Gas compression location always classifies as critical and hazard zone due to high process parameters mainly pressure, temperature and due to gas properties. In addition, gas plants are critical due to suspected impact to human health, safety and environment at particular level of incidents or leaks may happen. In addition, to consider the cost of the compression equipment which are unique and customized based on particular design conditions. Therefore, some studies are conducted mainly for gas equipment condition monitoring (CM) and focused to repair the common frequent failures in gas compression equipment, but limited studies were focused in gas plant maintenance management or to develop the applied maintenance system, strategic plans, risk based inspection (RBI) for the gas compression plant in order to maximize the integrity and reliability levels and the overall equipment effectiveness (OEE) with resources optimization.

This paper presents the literature reviewing of recent relevant contexts and studies in the maintenance systems and condition monitoring for gas compression plants use reciprocating compressors.

Keyword: Condition monitoring, Gas Plant, Reciprocating Gas Compressors, Modern Maintenance, Maintenance Management

1. INTRODUCTION

In general, gas compression plant is a specific plant usually constructed for gas production fields, oil processing facilities, refineries and in limited manufacturing premises use the compressed gases. Compression unit requires for gas handling to subsequent stages and for gas transportation by using suitable type of compression systems. Compressors are the main unit in gas plant work with comprehensive systems mainly include the followings:-

1) Compressor driving system (electric motor, turbine or engine)
2) Lubrication loop system
3) Piping, scrubbers and pulsation vessels
4) Cooling systems
5) Instrument and control systems (for operation, monitoring, protection and control).

Investment in gas industries is attractive due to continuous demand of gas and its products as well it has almost a stable global prices. In fact, gas plants operate with high operating parameters which lead to have high attention during operation, maintenance and inspection to avoid any associated risks may occur. There are several types of gas compressors. [1] He explained in details the common types of reciprocating gas compressors and their advantages and disadvantages.

Compressor's condition has a gradual degradation on its performance. Degradation may happen due to life cycle, operating condition, non-efficient operation and maintenance procedures or due to manufacturing quality. In case of any incident or gas leak, it may cause harm to the working team, equipment, environment, plant process. So, any down time in gas plant will not be ordinary and also affects the investor's revenues.

Maintenance and inspection programs are vital for such areas to ensure having efficient plant and safe working location with minimum downtime. Normally, working team follow the manufacturer recommendations and standard practices. Recently, some studies conducted for compressors to increase the condition monitoring on the compressors to predict failures at earlier stages. Moreover, prognoses any abnormalities to be recorded in planned maintenance work rather than having any unexpected failure. Also, limited studies went through the modern maintenance engineering practices to come with high equipment effectiveness.

This paper reviews the recent performed studies in modern condition monitoring maintenance and the applied maintenance engineering practices for reciprocating gas compressors in order to enhance the condition monitoring, risk elimination and increase the overall equipment effectiveness for further studies in gas compression plants.

2. REVIEW OF PREVIOUS STUDIES IN RECIPROCATING GAS COMPRESSORS

Reference to recent conducted researches in gas compression plants use gas reciprocating compressors type found the focused areas can be classified in two categories:-

2.1 Review of Condition monitoring and faults diagnosing Studies

[2-3] Their study described the effective application of an optimized condition based maintenance philosophy to reciprocating compressors on an offshore oil and gas company (FPSO) in the Northern Sea. Intrusive maintenance of these compressors obviously was required by analyzing the system data and focused on compressors valves temperature and monitor the rod positioning which conducted by the operator and a company named DEI. Mainly, after review found the oil coolant in the packing rings had been incorrectly set causing high packing temp, thus watch keeping parameters installed to ensure coolant flowing and gave detection of incipient valves failures demonstration. Also, created a monitoring for the rod positioning system to monitor the wear in ring bands. Therefore, the set condition monitoring guided to call out the equipment manufacturer for overhauling at earliest time based on the monitoring trends and features and saved equipment from further damages.

[4] He studied one relevant effect of mechanical degradation causing a drop in the efficiency by the time. They used the general mixed integer nonlinear programming (MINLP) formulation for the simultaneous optimization of the operation and maintenance of a parallel connected compressors network. The case of condition-based maintenance and operational optimization compared with the applied preventive maintenance strategy for compressors efficiencies. The objective of the optimization was to reduce operational and maintenance cost for the network of air compressors which it is part of an air separation plant. The method used a mathematical modelling considered a fixed scheduling horizon that is divided into a set of uniform periods took into account the deterioration of the performance of a compressor over time. It compared the condition-based maintenance approach with a typical preventive maintenance case. The condition-based approach achieved reduction in the overall cost by 11 %, especially in the start-up, shut-down and maintenance costs compared to the benchmark preventive maintenance strategy.

Most of compressors concerns coming into the excessive vibration which will impact the compressor, pipes and auxiliaries as well some parts may affect due to high temperature. The cause of severe vibration problem was also investigated and used a model analysis, piping re-calculation and velocity frequency spectrum analysis and pressure pulsation measurement [5]. They found that the inlet pipelines avoided low frequency resonance region and the actual length of the inlet pipelines was in the second resonant piping length. Also, the pressure pulsation was 34.26 mm/s which far exceeded the standard API 618 that is 17.8 mm/s. The results indicated that large pressure pulsation and acoustic resonance occurred on the inlet pipelines were the key factors inducing vibration. Vibration elimination treatments included enlarging the buffer volume of gathering manifold, adjusting the inlet piping length to avoid acoustic resonance and increasing the curvature radius of bend. After remodeling of the inlet pipelines, the test data indicated that the vibration level of the inlet pipelines reduced to an acceptable level and reduced the vibration sources.

[6-7] they presented in their study the statistics of faults and analyzed vibro-activity of reciprocating compressor valves as one of the most often failed components. The data were provided by one of the Russian oil refineries and resulted that five systems and components of compressors caused about 76.5% of all unplanned compressors shutdowns. Faults of valves made up to 36% of total faults and consumed 50% of the total repair costs. However, piston-cylinder units caused a significant percentage (over 30%) of all faults, where the ring failures were more than 25% .Special research in gas flow through the valves helped to find solutions to form gas flows and controlled gas dynamics conducted by the specialists of KSK-Service company and implemented the solution. Specialists designed a poppet spring less valve and ensured laminar flow of gas passing through the valve. Experimental study significantly increased the valve life and improved its vibroacoustic characteristics.

[8] They investigated the effects of pressure pulsations on reciprocating natural gas compressor performance thermodynamically and used a nonlinear model of hybrid numerical. Their Model considered the interaction between the compressor and the pipeline system. Through the study's examination of the pressure pulsation influence, it was observed in the suction system that the first harmonic response reduced the mass flow rate but significantly increased specific work. Similarly, the second harmonic response had a strong supercharging effect, but the specific work increased slightly. Model developed and achieved the mutual interaction of the two systems. So, the Study assessed the predicted hybrid numerical model and concluded that in-cylinder temperature for the real gas model was about 5.9 K temperature higher than used ideal gas model during the compression and the discharge phases, because of the mass flow rate. Also, it provided more response in harmonic responses in the suction and discharge systems.

Also, a study examined the reliability impact as a result of upgrading the temperature monitoring devices on the connecting rods of electric driven reciprocating compressors [9]. In addition to that, the cost analysis presented to demonstrate the upgrades in hardware and software which eventually yield saving in the operating cost. The studied compressors used eutectic temperature sensors in the connecting rods, but the study proposed upgrading in temperature sensors which consisted of a wireless radar system without the need of an external power source. The wireless sensor replaced the eutectic device in the connecting rod's thermowell. An antenna replaced the pneumatic switch and received timely a signal from the wireless sensor once per revolution. The processing unit software calculated the

temperature and transmitted into the supervisory control and data acquisition (SCADA) system. The study resulted a better on-time update in the temperature monitoring on the connecting rods of the reciprocating compressors.

Furthermore, a study resulted that five vibroacoustic signal sensors on reciprocating compressors (Cylinder, pressure inlet valves, crosshead, fundamental bearing and the shaft angle position) sensors could form fifteen diagnostic parameters of signals in case of malfunctions according to the signal of each sensor [10]. Using of these parameters signals system diagnostics and monitoring on unconditional algorithm automatically determined 36 causes' vibrational activities in reciprocating compressors. The result of monitoring provided more control of almost 80% bounce of commonly occurring failures.

The compressor's valves are the weakest component in the compressor and being the most frequent failing element and accounting for almost half of the maintenance cost. Study used data for valve temperature and presented the combination of algorithms analysis output by using several methods such as multiple linear regression, polynomial regression, K-Nearest Neighbors Regression (KNNR) along with remain useful life method (RUL) [11].The algorithm analysis was used to assess the valve failure conditions. The result showed that all performed methods compared well in qualitative (graphs) and quantitative (metric) analysis. It demonstrated that all methods were able to cope with instantaneous nature of failure mode which meant the deterioration of the valve health was highly depend on operating environment conditions.

[12] They focused on pressure pulsations in the piping system of the reciprocating compressor that produced excessive noise and even led damaging the piping and machinery.

The finite disturbance theory was used to solve the nonlinear partial differential equations for the unsteady one-dimensional compressible gas flow in the complex piping system by predicting the large amplitudes of pressure pulsations in the piping system. The result of the experiment showed that the finite disturbance theory was more precise than the acoustic method in large amplitude pressure pulsation because the acoustic theory neglected the second order terms which brought by the disturbance in the continuity and Euler equations as a linear equation. So, the result was only an approximation (not a precise solution) .The difference between the value of calculation and the value of experiment using the finite disturbance theory found to be 15%, moreover, the same difference by using the acoustic wave theory found to be 77%(better to right the difference between the calculations was xxx) . Thus, it suggested that when pulsation pressure/average pulsation ratio is greater than 8%, the acoustic wave theory would not provide a satisfactory solution to the problem.

An investigation of using a volume low-pass filter for pulsation attenuation in a reciprocating compressor piping system were performed. Moreover, a study focused on its frequency response characteristics and influence on the actual attenuation effects [13]. A three-dimensional acoustic model of the gas pulsation established for a compressor discharge piping system with and without the volume choke-volume filter. It was based on which the gas column natural frequencies of the piping system and the pressure wave profiles predicted by means of the finite element method. The model validated by comparing the predicted results with the experimental data. The results showed that the characteristic frequency of the filter was sensitive to both diameter and length of the choke but independent of the parameters of the piping beyond the filter. The pressure pulsation levels in the piping system downstream of the filter were significantly attenuated especially for the pulsation components at frequencies above the filter's characteristic frequency. It resulted the measured peak-to-peak pressure pulsation at the outlet of the filter was approximately 61.7% lower than that of the surge bottle with the same volume.

[14] They elaborated more in fault diagnosing of reciprocating compressor valves by using an integrating method of acoustic emission signal to simulate the valve motion which evaluated the current valve condition and predicted the expected condition based on generated trends and curves of working conditions.

It is necessary to have a proactive maintenance program in order to avoid abnormal conditions, failures and incidents in gas plants equipment. [15] They introduced a case study on the development of a condition base maintenance system (CBMS) for an oil and gas offshore plant at a liquefied natural gas (LNG) floating production storage and offloading vessel at FPSO field which using powerful compressors. Any unexpected or prolonged downtime of these units has a large impact on plant availability. The study identified and solved problems in advance before damage to equipment occurred by detecting abnormal states of shaft vibration throughout sensor data monitoring, diagnosing abnormal types, predicting remaining useful life. It undertook the proactive maintenance by building a system architecture, work flow, event, test algorithm and established the diagnosing and prognostic modules. Such intelligent diagnostics criterion was more advanced technique than the conventional method which widely used in condition monitoring as well resulted on time and accurate feedback.

Furthermore, a fault-diagnosis system proposed by using machine learning techniques to detect potential faults for compressors by [16] . The system evaluated by using an operation data collected from China National Offshore Oil Corporation (CNOOC) .The analyzed data demonstrated that the system could efficiently diagnose the potential faults in compressors with 80% accuracy. Several method used parameter such as pressure, temperature, vibration, and acoustic emission (AE) signals to diagnose faults in reciprocating compressors. Two types of data were obtained from compressors which structured and unstructured data. Structured data related to the status of compressors such as temperature, speed, and acceleration, but unstructured data are from video surveillance. Study focused on analyzing structured data. All experiments were generated by using software "Matlab 2014a" and "Visual Studio 2013" community edition mixed in a private cloud with 300 servers. It resulted and indicated that the system identified most of the faults automatically with more than 80% accuracy.

2.2. Review of Applied Maintenance Engineering Studies

A collaboration made with a private company named RC to analyze the behavior of their used reciprocating compressor and aimed to identify and evaluate the effects of reliability, availability and maintainability (RAM) [17]. Study presented

the most relevant aspects and findings by assessing the operational performance of reciprocating compressor system .Also, it reviewed the maintenance activities, outlined failures and main events contributing to jeopardize the production process. It highlighted the generated preventive maintenance tasks and planning on reciprocating compressor API 618 and recognized the needs for a structural approach to implement RAM. The used methodology was the bibliographical research, documentary and content analysis of soring most of maintenance problems. Research output reflected the importance of using RAM for plant lifecycle control and reviewed the RAM performance as well highlighted the usefulness of learning RAM principles to the process engineers to apply.

The integrity management defined as a kind of advance risk prevention and risk management method. [18] They made a study on risk based inspection (RBI) method for gas compressor station and reflected the applied integrity management of a gas compressor station was insufficient. Thus, he reviewed the basic principle of risk based inspection (RBI) in the gas compressor station and determined the corrosion mechanism and process loops. The probability of failure calculated by using the modified coefficient and the consequence of failure determined by the quantitative method. Effective measures took to eliminate the impact of risk. The results showed the cumulative risk and average risk were much higher which mainly due to the potential of piping and equipment for sulfide stress corrosion cracking. According to the analysis output, it found that about 10% of the compressor accounted for about 80% of all the risk in the plant and by developing a targeted inspection plan would effectively control the risk and reduce costs.

Besides that, a study focused on the methodology of improving the productivity through overall equipment effectiveness (OEE) with the help of lean manufacturing technique in compressor manufacturing industries [19]. Lean manufacturing technique is used to identify the waste, losses and eliminate it from the process. The study carried on two high pressure air compressor manufacturing unit and addressed in three aspects namely the availability, performance and quality which quantify OEE. The investigation result showed that the OEE has been improved from 45.9% to 55.8% by investigated the influence of the overall equipment effectiveness which compared before and after implementing the lean tools. The end results gained 75% reduction of tool searching time, 23% of down time and productivity has been increased in range of 12.5% and overall equipment effectiveness had increased by 17.7%. The below equations were used to obtain the overall equipment effectiveness (OEE):-

$$Availability = \frac{Operating\ time}{Total\ available\ time - Planned\ down\ time} \quad (1)$$

It considered the performance rate as production time of net output of equipment to its entire availability time as per below description:-

$$Performance = \frac{Ideal\ cycle\ time * Total\ cycle\ time}{Operating\ time} \quad (2)$$

$$Quality = \frac{Total\ Parts\ run - Total\ defects}{Total\ Parts\ run} \quad (3)$$

$$OEE = Availability * Performance * Quality \quad (4)$$

Iran khodro is one of the largest manufacturing company in Iran and in the Middle East. In order to optimize its production lines, electricity had been substituted by compressed air power. [20] They investigated the status of the equipment and proposed new definitions and changes in OEE parameters. There was no Q (quality) factor for OEE calculation, because the point of measurement of the volumetric flow was exactly at the outlet of the compressor and there was no rejected air. Therefore, in the calculations for the OEE index instead of having three components, only two were considered which availability (A) and Performance (P).The calculation considered a schedule time as 365 days a year and 24 hour a day. In order to assure the calculations were made to possible real value, study recommended to multiply the OEE with capacity coefficient factor. Therefore, the used equations were as in below:-

$$Capacity\ coefficient = \frac{Actual\ capacity}{Nominal\ capacity} \quad (5)$$

The used OEE% equation was in below:-

$$OEE\% = \frac{Load\ time * Capacity\ coefficient}{365\ days\ of\ year} * 100\% \quad (6)$$

4. RESULT

Reciprocating gas compressor is a main unit in the gas compression plant, but the plant contains another equipment and auxiliary systems which have same importance to achieve gas compression function in safe mode. This review is carried on the recent studies in reciprocating compressors use in gas compression plants. The review is sorted into two areas which are the condition monitoring and faults diagnosing studies and for the applied maintenance engineering researches mainly RBI, RAM and OEE.

Each type of applied maintenance engineering studies has its related direct and in direct merits on plant enhancement individually based on the gained result from each application. Most likely, in such critical gas compression plant an implementation of multi maintenance engineering system will be better because most of the recorded incidents were occurred due to lack of particular type of maintenance outcomes.

4. CONCLUSION

At present, the investment in gas industries has high benefits and can generate enormous profits. Thus, recently several studies were focused and conducted in the compressors of gas plants. A lot of problems have been solved in reciprocating gas compressors though the gain results of the researchers. In general, the previous studies focused in particular areas on the reciprocating compressors as in below:-

1) Studies performed to repair most frequent failed items.

2) Enhance condition monitoring techniques for earlier prognosis and failures prediction mainly for temperature and vibration monitoring as well bearing and valves prognosis.
3) Very limited studies were carried on OEE enhancement and RBI for gas reciprocating compressors.

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