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Condition Based Maintenance (CBM) in the Oil and Gas Industry: An Overview of Methods and Techniques

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Abstract

On and offshore development projects in the oil and gas industry are predominantly capital-intensive investments, with the potential for serious financial and environmental consequences should a catastrophic failure occur. Therefore, an efficient as well as effective maintenance management approach is essential to the continuation of production in a safe and reliable manner. This paper explores the existing literature on the development and applications of CBM in the oil and gas industry. The recent literature reinforces the fact that the role of CBM is critical to the smooth, uninterrupted, efficient and safe running of oil and gas facilities. The complex and integrated nature of the oil and gas facilities require specific and carefully prepared CBM programs with real-time condition monitoring data recording, analysis, and decision making to facilitate an accurate understanding of the essential maintenance intervals. This in turn can promote optimised utilization of plant equipment with higher levels of certainty and safety.

Keywords: condition-based maintenance, condition monitoring, predictive maintenance.

1. Introduction

Emerging challenges in the oil and gas industry are proving to be a catalyst for change in the management of facilities, new and old, worldwide. The growth in demand for crude oil and natural gas is unlikely to show any significant signs of slowing over the next decade or more, but the reality is that companies are faced with greater extraction costs due to: (1) the increasing scarcity of conventional crude oil and natural gas reserves, and (2) the difficulties associated with the extraction and/or processing of unconventional reserves found in oil sands, coal seam gas (CSG), shale gas [1], underground coal gas (UCG) [2], and reserves located in the depths of the oceans. Similarly, as sources mature, flow slows and costs increase as advanced technologies are required to enhance recovery. Another challenge, common to all industries, is the optimisation of equipment availability versus costs. Furthermore, due to the highly critical nature of the oil and gas activities, the industry cannot afford unexpected failures.

Many companies are investigating the broader implementation of automation to reduce the number of employees required and the risks they are subjected to in a bid to improve efficiency and decrease human error and risks. There is also an increase in un-manned facilities, particularly in remote locations. These two trends will inevitably increase operating costs. From an investment perspective, the uncertainty in supply means that investors will be looking to low cost of production and maintenance operations to ensure the safety of their investment [3]. Due to these trends and challenges, oil and gas companies are looking to optimise production [4] and improve asset integrity management [5]. An effective maintenance program is an essential and significant component of operations with many benefits, including; the reduction of downtime due to unexpected equipment failure, which improves reliability and maintainability, increasing equipment availability and utilisation. Optimising maintenance also improves the useful life of equipment.

Proactive or preventative maintenance (PM) strategies are an essential component of an effective maintenance program. The PM strategy known as condition-based maintenance (CBM) provides a dynamic understanding of equipment condition while in operation and is used to predict failure in mechanical systems through fault diagnosis from condition monitoring signals using diagnostics and prognostics [6]. CBM strategies are currently a major focus of maintenance and maintenance management research due to the aforementioned trends and challenges, increased complexity in industrial technologies [7], and advances in condition monitoring techniques that include the use of online systems [8]. Current literature on CBM applications in the oil and gas industry illustrates the effectiveness of this strategy as a way to improve maintenance management, prevent accidents, and optimise production [9].

2. CBM in the Oil & Gas Industry

Oil and gas projects are particularly capital-intensive investments; with the potential for serious financial and environmental consequences should a catastrophic failure occur. Consequently, maintenance management is essential to the continuation of production in a safe and reliable manner [10]. CBM is currently being utilised in the petrochemical industry, with condition monitoring of both on and offshore oil and gas wells, according to one source, generating additional production benefits in the range of 5% [11]. The oil and gas industry trades primarily in raw fossil fuels known as primary energy sources. Colley and associates [12] focus on optimising energy consumption of upstream oil and gas facilities to reduce operating costs, increase revenues, and address greenhouse gas emissions; suggesting that monitoring the 'energy intensity trend' can provide guidance for maintenance management programs. This is due to maintenance management having a direct affect on energy consumption and optimisation in oil and gas facilities.

Along with the large and complex machinery and equipment, another characteristic of such facilities is a relatively small workforce. A benefit of an efficient CBM strategy in this case is that condition data reaches the relevant people and maintenance activities can be concentrated where and when they are required. Information and communication technologies (ICT's) are allowing large companies to develop central maintenance hubs that monitor remote facilities; alerting and providing assistance to onsite maintenance personnel [13]. Remote facilities are often more frequently located offshore in deep water. The significant difficulties associated with the inspection of offshore oil and gas production facilities in deep water emphasizes the importance of permanent condition monitoring devices [14].

Corrosion is a major concern in both onshore and offshore oil and gas facilities. De Bruyn [15] argues for the need to predict and measure materials degradation due to corrosion, providing an overview of traditional and modern corrosion monitoring techniques and trends relevant to the petrochemical industry. Well faults are another sources of failure in oil and gas extraction facilities, which include sanding and slugging [11].

Petroleum refineries and gas processing plants are large and complex operations with many systems and subsystems operating simultaneously. Within and in-between each system/subsystem are: separators, heat exchangers (condensers, boilers, and re-boilers), valves, scrubbers, accumulators, piping systems, and rotating mechanical systems (induction motors, compressors, pumps, etc). Each of these components has the potential to effect production, cause health and safety issues, and/or increase the environmental impact of the operations should failure occur. In some instances it is feasible to have standby components, but in other cases the machinery or equipment is too large, expensive, and/or complex; these machinery and equipment are often the most suitable for CBM.

There are numerous individual processes within an oil refinery, as illustrated in the schematic flow diagram of a typical oil refinery shown in Figure 1. Depicted in the diagram are the various processes that occur in-between the crude oil feedstock and the end products. It does not include any of the facilities that provide utilities such as steam, cooling water, electric power, and hydrogen. Outlets marked 'gas' represent pipelines to the gas processing plant, shown in Figure 2; which provides a schematic flow diagram of a typical natural gas processing plant, depicting the various processes that occur between the inlet gas and liquids feedstock, and the final end products. The diagram describes only one of the many different gas processing configurations and does not include any of the facilities providing utilities such as steam, cooling water, and electric power. The planning of plant design is complex and the final solution often differs [16].

Common to most of the processes is the use of pumps, compressors, and heat exchangers [17]. These intermediary components are utilised to control process parameters, such as; flow rates, pressure, and temperature. Azadeh and associates [18] suggest that major equipment failures in similar plants are generally related to pumps, compressors and piping; and there is a reasonable amount of CBM literature relating to all these common components. A closer look at the literature relevant to these and other more substantial plant and equipment is to be further investigated.

2.1 Rotating Mechanical Systems

Rotating mechanical systems are found in the majority of industrial processing facilities, including oil and gas facilities. Condition monitoring of these systems, particularly vibration monitoring, helps prevent losses caused by unbalanced forces, misalignment, improper lubrication of ball bearings, metal fatigue and cracks occurring in welded or constructed parts, and/or locking of the ball bearings due to excessive heating [19]. Ebersbach and Peng [20] explore the use of expert systems with vibration analysis to help prevent these losses; while Saxena and Saad [21] have evolved an artificial neural network classifier for condition monitoring of rotating mechanical systems.

2.2 Pumps and Compressors

Pumps and their associated systems are essential in oil and gas facilities for the efficient transportation of fluids. Common pumps found in these facilities include: centrifugal, reciprocating, diaphragm, and rotary pumps [22]. The condition monitoring of pumps and their associated systems is an established application of CBM and is an existing area of research [23]. Rohlfing [24] provides three examples in the oil and gas industry where pump CBM has been effectively implemented. Azadeh and associates [18] have developed a diagnostic mechanism for pump failures in which pump operating problems fall into two categorises: (1) Hydraulic problems that suggest the pump may fail to deliver liquid, deliver insufficient capacity, develop insufficient pressure, or lose its prime at starting, and (2) Mechanical problems that are characterised by the consumption of excessive power or development of mechanical difficulties at the seal chambers, or bearings; in either case vibration, noise, or breakage may occur. Fatigue is a common cause of pump failure [25, 26].

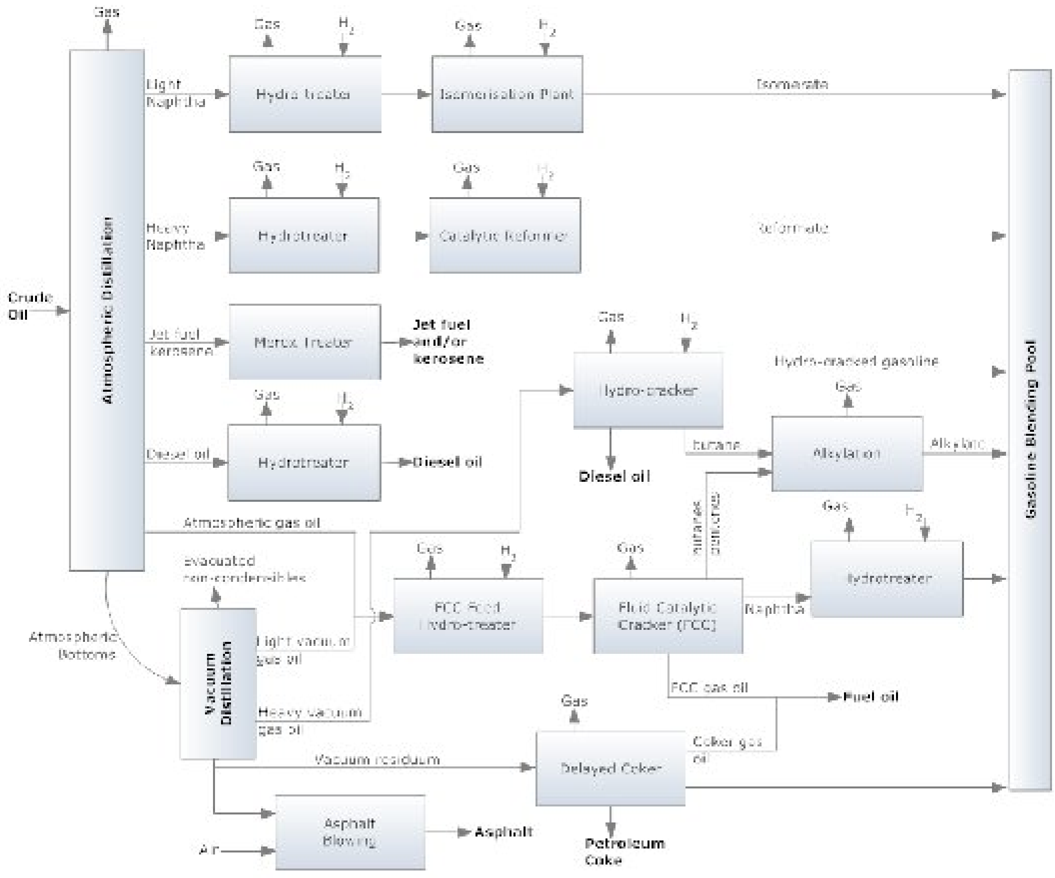

Figure 1: Block schematic overview of oil refinery [27]

Vibration monitoring is particularly suited to pumps due to the number of integrated rotating parts, which may show additional movement when faults develop [28]. A more recent development in pump condition monitoring is the application of ultrasonic sensors [29]; introducing a new ultrasonic measurement based on acoustic emission analyses for high pressure process pumps. Permanently fixed condition monitoring sensors are particularly well suited to applications in hazardous, corrosive, or inaccessible environments, and where pumps are permanently submerged [28].

Pressure is a common process parameter that varies depending on the requirements or stage of the process or operation. The purpose of a compressor is to raise the pressure or energy within a fluid. This is a common practice in oil and gas processes. The two basic types of compressors used in production facilities are reciprocating and centrifugal compressors [22]. In Carnero's [30] development of a model for selection of diagnostic techniques & instrumentation in a predictive maintenance program; the case study utilises a screw compressor with integrated lubricant and vibration analysis.

2.3 Rolling Element Bearings

Rolling element bearings are frequently encountered in rotating mechanical systems due to their carrying capacity and low-friction characteristics. These bearings come in a range of sizes from very small to extremely large. A number of condition monitoring techniques are applicable to rolling element bearings, as the literature suggests. Orhan and associates [31] present an interesting three part case study on the application of vibration monitoring and analysis carried out on rolling element bearings in machinery at a petroleum refinery. Further discussions on the application of vibration monitoring to rolling element bearings may be found in: [32, 33].

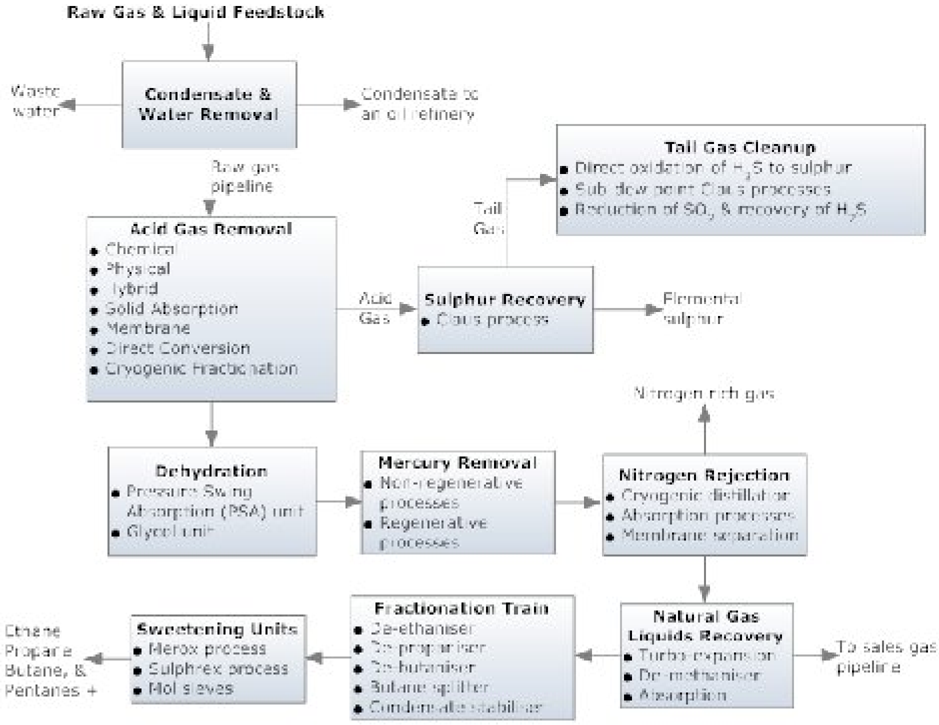

Figure 2: Block schematic overview of gas processing plant [34]

The application of integrated condition monitoring techniques has proven to be another area of research relating to rolling element bearings. Harvey and associates [35] investigated wear characteristics of tapered roller bearings using electrostatic sensors, vibration, and lubricant temperature measurement, with eddy current technology and ferromagnetism to sense debris in the lubricant recirculating system. A similar paper by Craig and associates [36] incorporated electrostatic wear-site sensors to identify charge during surface wear, a vibration accelerometer, thermocouples, inductive and ferromagnetic particle counters, and oil-line sensors to detect debris in oil scavenging lines. Yang and associates [37] present the application of a new time-frequency processing technique, known as basis pursuit, for the extraction of features from signals collected from faulty rolling bearings. A clearer picture of bearing condition can be obtained by integrating a range of condition monitoring techniques.

2.4 Pipelines

Pipelines enable oil, gas, steam, and other materials to be transported to and around processing plants and refineries. Reliability of pipelines in industry is further discussed by Sun and associates [38]. In a technical paper by Yan and Chyan [39] investigates the suppression of unfavourable fibre optic non-linearity in oil and gas pipeline monitoring systems utilising fibre optic sensors capable of measuring temperature and strain. These systems provide pipeline distributed structural health information that can give early warnings of degradation i.e., corrosion and/or the forming of hydrates, which can lead to catastrophic failure such as pipeline explosion or leakage. One method for detecting leakage is ultrasonic condition monitoring [40]. In many oil and gas facilities, failures such as leaks, can result in increased pollution; establishing a direct link between maintenance management and pollution [41]. Caputo and Pelagagge [42] identify the main causes of leakage as: external interference or third party activities, corrosion, construction defects, mechanical or material failure, ground movements and natural hazards, and operational errors. Pipeline integrity management [43] is an essential component of maintenance management.

2.5 Induction Motors and Gearboxes

In the oil and gas industry, as in most industries, induction motors are a core piece of machinery as they are versatile and rugged [44]. Within an oil or gas refinery induction motors supply rotational mechanical power to numerous systems, large and small; and are therefore a focus of research [45]. CBM policies utilising performance parameter analyses, via motor current signature analysis (MCSA), have been established [46, 47].

In most rotating systems, there is a need to transfer power to a lower rotational speed, with greater torque, in the most efficient and economical manner; this is the function of a gearbox. Gearboxes are an important machinery component in any industry; any defect in the gears may lead to machine downtime resulting in a loss of production. Common condition monitoring techniques for gearboxes include wear debris and vibration [48, 49]. Kar and Mohanty [50] provide a comparison of vibration techniques and a new non-intrusive method for detecting fluctuations in gear load that utilises MCSA.

2.6 Oil/Water Separators and Heat Exchangers

A number of oil/water separators are utilised for cleaning water in oil and gas facilities including, filters, precipitators, skim tanks and vessels, plate coalescers, flotation units (dissolved gas and dispersed gas), and serpentine-pipe packs [51]. A more recent development in the oil and gas industry is the use of hydro-cyclones for de-oiling. As existing oil and gas fields reach maturity, there is a tendency towards a greater percentage of water in the extracted oil/water/gas mix, increasing the need for these secondary de-oiling systems. Bennett and Williams [52] describe the development and application of an industrial de-oiling hydro-cyclone utilising electrical resistance tomography (ERT) condition monitoring. It is also important to accurately detect phases within the separator to improve the operational efficiency [53]. Sulphur dioxide in gas streams is another parameter that is regularly monitored [54].

Heat exchangers and heat exchanger networks can be found in most major processes within oil and gas processing facilities, such as the distillation process and reactors. They are employed to recover heat and therefore save energy. A major concern with heat exchangers is fouling, which has both thermal and hydraulic impacts on the system; slowing both heat transfer and fluid flow. Fouling deposition can reduce the cross-sectional area available for flow, change the surface roughness of the tube/duct, and block individual tubes completely, causing flow distribution problems [55].

Process parameter techniques that monitor the four inlet and outlet temperatures can be utilised [56]. Sikos and Klemes [57] select a heat exchanger network of a petroleum refinery plant to demonstrate the capabilities of their proposed methodology for reliability, availability, and maintenance optimisation. Corrosion is commonly found in overhead condensing systems of atmospheric distillation units as a result of the presence of three phases; liquid hydrocarbon, aqueous and vapour. It is possible to study corrosion control in overhead condensing units using laboratory devices that monitor corrosion by the potentio-dynamic polarization technique and dissolved iron analysis using inductively coupled plasma atomic emission spectroscopy.

2.7 Dehydration Plants and Fluid Catalytic Cracking

The gas dehydration process involves the removal of water vapour from the natural gas stream to meet sales specifications or other downstream process requirements such as for gas liquid recovery. Water vapour increases natural gases' corrosiveness, particularly when sour gases are present, such as Hydrogen sulphide (H_2S) and carbon dioxide (CO_2). High moisture levels in natural gas can also promote hydrate formations. There are two types of desiccant dehydrators utilised in industry. Firstly, a solid desiccant dehydrator, possibly using silica gel, due to its ability to provide extremely low dew points [58]; and secondly, a liquid desiccant dehydrator, possibly using tri-ethylene glycol (TEG), known as a TEG-dehydration plant [59].

Fluid catalytic cracking (FCC) is the thermal decomposition of petroleum hydrocarbons in the presence of a catalyst [27]; it is the most important and widely used refinery process for converting heavy oils into more valuable products like gas, liquefied petroleum gas, gasoline, and gas oil. Important process parameters utilised for condition monitoring of FCC include: reaction temperature, feed stock preheat temperature, and pressure. Similar parameters were used by McGreavy and associates [60] to help demonstrate how neural networks can be used as an operational support tool for industrial FCC units. Pedregal and Carnero [61] developed a forecasting system in condition monitoring based on vibration signals in order to improve the diagnosis of a critical component belonging to a retarded cracking unit; as a cracking unit is critical to continued production.

3 Environmental factors

As oil and gas facilities migrate into increasingly hostile environments, the role of CBM will be paramount to their success in maintaining operation and production levels. Firstly, the frequency of maintenance intervals is likely to be different from facilities in more accommodating environments; and secondly, the efficiency and effectiveness of maintenance support services and delivery of supplies may be affected [62]. This highlights the need for real-time condition monitoring data to develop an understanding of the differing maintenance intervals, MTTF, and MTBF; to provide greater lead times for maintenance requirements and activities. However, caution must be exercised when selecting condition indicators as those that are sensitive to environmental or operational variables will inevitably produce condition monitoring data that may mislead subsequent analyses [63]. Automation of petroleum production and separation facilities is desirable as plants become more frequently located in remote areas that are difficult to access [64]. The application of CBM in the oil and gas industry is clearly a valuable tool for maintenance management, both in existing facilities and in future developments with new and varying challenges. The development of applicable CBM tools and techniques is essential for optimising utility in the oil and gas industry.

4 Conclusion

The study has provided a comprehensive platform for the selection, further investigation and adoption of condition based maintenance strategies applicable to the oil and gas industry. It uncovers the fact that the role of CBM is extremely critical to the smooth, uninterrupted, efficient and safe running of oil and gas facilities. The oil and gas plants require more specific and carefully prepared CBM programs, which incorporate real-time condition monitoring data recording, analysis and decision making to facilitate a more realistic understanding of the differing maintenance intervals. This would in turn promote optimised utilization of plant equipment with higher levels of certainty and safety. Future research into the application and integration of condition based maintenance technologies specific to the oil and gas industry would assist with the development of industry specific condition based maintenance packages for use in the field.

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