Journal of Natural Gas Science and Engineering 25 (2015) 66–76

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Review article

# Review of black powder in gas pipelines – An industrial perspective

Tariq S. Khan*, Mohamed S. Al-Shehhi

*Department of Mechanical Engineering, The Petroleum Institute, United Arab Emirates*

ARTICLE INFO

*Article history:*
Received 1 December 2014
Received in revised form
15 April 2015
Accepted 17 April 2015
Available online 15 May 2015

*Keywords:*
Natural gas
Black powder
Pipelines contamination
Characterization

ABSTRACT

Natural gas is extensively used in energy production, process industry and domestic applications across the globe. Black powder has been identified as a major operational problem faced by the gas industry today. A detailed literature review was carried out to report recent studies on black powder phenomenon in the gas pipelines. Focus has been on reporting research studies conducted at industrial level. Presence of black powder causes product contamination, erosion, clogging, fouling and flow reduction in the pipelines. Sitting black powder may cause operational problems, but its movement with gas flow poses even bigger challenge. A substantial amount of work has been reported on characterization and removal of black powder. The current review highlights research gaps and recommends quantifying effects of several operational and geometric parameters to better understand and manage black powder in gas pipelines.



## 1. Introduction

In today's technological world natural gas is widely used in power generation, industrial feed stock for making products such as plastics, fertilizers and domestic applications. As per US energy information agency statistics, more than 22% of the total world energy is produced by natural gas (EIA, 2013a). The requirements are ever increasing with rapidly growing population of the world. The world's total energy produced in year 2013 is about 547 quadrillion Btu and this is expected to reach 630 quadrillion Btu in year 2020. Fig. 1 below give an insight into world energy balance and share of natural gas in the total produced energy.

Evolution and expansion of long pipelines is necessary to keep pace with demands. These pipelines are critical link between gas sources and market areas. These are unique in many ways like, diameter, material and high operating pressure and temperature.

Black powder is a generic name used to loosely represent a material that is generated inside gas pipelines. It is a common pipeline contamination problem all over the world, yet not well understood today in terms of its formation, inhibition, detection, removal and monetary loss. Though a considerable research work has been reported in open literature, however, a lot of variability still exists. Different gas pipeline operators report different compositions for the black powder removed from their pipelines. Depending on the operating conditions and data analysis, some researchers report black powder to be dominated by iron sulfide (Baldwin, 1998) while some argue that it is predominantly different forms of iron oxides and not FeS (Godoy et al., 2005; Tsochatzidis and Maroulis, 2007). Another group reports a combination of both (Arrington, 2006; Saremi and Kazemi, 2011). Though, several studies have been carried out to determine the sources of black powder, its prevention and removal but still a lot of work needs to be done in order to further understand and control the black powder contamination in gas pipelines. Black powder may be found in wet and dry forms. It may be considered a mix of iron sulfides, carbonates and oxides found in gas pipelines. Though, the sources of black powder are still not very clear, some major known sources are; mill-scale coming from pipe manufacturers and corrosion products, salts and scales from gas wells, wet gas gathering systems and rusting, flash rust and carry over from gas collection systems. Black powder may mix mechanically or combined chemically with any number of contaminants. Black powder may be found in various sizes, from as small as 0.01 μm up to 1000 μm (Smart, 2011). However, most of the studies reported black powder particle's average size to lie between 0.1 μm and 300 μm (Saremi and Kazemi, 2011; Powell and et al., 2012; Sherik et al., 2008b; Smart, 2007).

Black powder contamination may be prevented by removing mill scale and hydro-test water from newly installed pipelines. Addition of corrosion inhibitors, use of filters before compressors and process plants can help reduce chances of black powder contamination.

* Corresponding author.
*E-mail address:* tkhan@pi.ac.ae (T.S. Khan).

http://dx.doi.org/10.1016/j.jngse.2015.04.025
1875-5100/

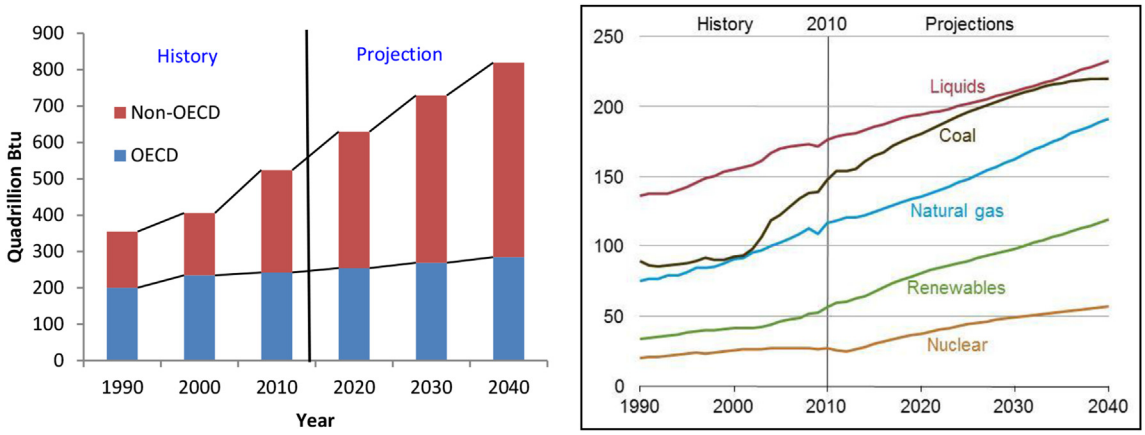


**Fig. 1.** World energy consumption (general and by fuel) (EIA, 2013a).

The removal of black powder from pipelines is reasonably well established. The current removal techniques include chemical and physical removal. Most chemical cleaning processes are water based with additional cost of drying the pipeline. The chemical cleaning is usually considered economically expensive option for removal of black powder (Improved black powder rem, 2005). Some of the well-known physical cleaning procedures include; pigging and high velocity flushing, pigging with solvents and gel pigging. Nevertheless, there is no single universal solution available that could be used in removal of black powder from pipelines. Even a small improvement can save a noticeable amount of energy on the global scale.

Another contamination issue with gas pipelines is presence of radioactive materials in gas. The first traces of radioactivity study associated with natural gas could be found in early twentieth century by Mclennan in 1904 (McLennan, 1904). Mclennan analyzed radon content in some natural gas samples from Canada. However, it was only in 1971 that presence of Radon in natural gas was conceived to be a serious health hazard (Gray, 1990). Nevertheless, since Radon's boiling point lies between ethane and propane bulk of the Radon is removed during processing of natural gas (Gray, 1990, 1993). Saudi Aramco's environmental protection department has discovered presence of certain levels of naturally occurring radioactive materials (NORM) in their oil and gas processing equipment. Presence of such materials created a potential hazard to their manpower, public and environment. So recently Saudi Aramco has developed a NORM management strategy. This management tool defines the NORM exemption levels in their operations, provides guidelines for NORM monitoring, identification and assessment of risks involved, control measures, storage and disposal procedures (Cowie and et al., 2012).

This paper provides a review of the up to date research work conducted mainly at the industrial level on black powder issue in gas pipelines. Emphasis is placed on gathering works of technical community across the oil and gas sector of the world. Based on the available literature important conclusions are drawn and recommendation made for future work. While the black powder sitting at the bottom of pipes can cause flow disturbance and blockage, it becomes more critical if it starts to move with gas flow (Smart, 2011). This movement of black powder can cause blockage of filters, valves, damage the instrumentation, cause erosion of pipe bends and above all the gas quality is severely compromised. Very few studies are conducted at industrial level to address this problem.

### 1.1. Effects of black powder

The presence of black powder in pipelines may cause several types of problems, including product contamination, wear, clogging and flow reduction in pipelines. Black powder may also represent a health and environmental issue. Hence presence of black powder decreases system efficiency, drastically effects quality of gas and increases corrosion/erosion rates.

Based on the available field data analysis, Jaime P. Perez (Jaime, 2011) tried to summarize the effects of presence of black powder on inline inspection (ILI) tools. He has shown that parameters like ILI tool's signal strength, speed, girth weld readings, rotation and inclination are affected due to presence of black powder in gas pipelines. He reported effect of black powder on ILI tool data accuracy from a 56 inch diameter sales gas pipeline. Low data density measured by ILI tool was attributed to tool lift-off due to presence of black powder on pipe surface. The author referred to an academic study (Francisco Valentine, 2000) that provides a good correlation between sensor lift-off phenomena and ILI tools data accuracy. This study has shown a drop in magnetic flux leakage as sensor is lifted off further away from the pipe wall surface. A major consequence of this inaccuracy is that the field verification of data becomes critical. It is well known that field verification is not only time consuming, but very expensive monetarily. Hence effectiveness of pipeline validation operation using ILI tools is more critical in the presence of black powder.

Lately, Sherik and El-Saadawy (Sherik and El-Saadawy, 2013) presented a study on erosion of control valves in gas pipelines that contain black powder. They have shown that the movement of larger particles leads to a larger degree of surface hardening than the smaller ones. The hardened surface layer leads to a lower intrinsic erosion rate when using larger particles and causes an increase in particle fragmentation which serves to further reduce the effective erosion rate. So it was concluded that the erosion behavior of pressure control valve materials cannot be predicted solely by the as-received bulk hardness of the material but hardening or softening of the surface layer of the material due to particle impingement will determine the erosion rate of the material.

Recently, Al-Jumaiya (Al-Jumayiah, 2013) has presented a case study of black powder problem on isolation gate valve of safety relief valve and the remedial action that has been taken to rectify this repeated problem at Saudi Aramco. The author highlighted safety issues related to this valve in presence of black powder. Safety relief valves are usually installed with an upstream block