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Process and metallurgical evaluation of outlet pigtails damage in the primary steam reformer of an industrial ammonia plant

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ABSTRACT

In spite of improvements in reformer tube metallurgy and manufacture, outlet pigtail tubes are now seen as a critical and weak link component of primary steam reformer in ammonia plants and often require replacement before the reformer tubes. The present work has been focused to find out causes of damaging 12 outlet pigtails of primary steam reformer in the ammonia plant of Shiraz Petrochemical Complex (SPC) after 7–8.5 years of operation from metallurgical and process point of view. A process evaluation based on operating variables and a detailed metallurgical investigation based on microstructural assessment, chemical and reduced thickness analysis, micro hardness measurements, metallography and tensile properties of pigtail samples has been performed. The obtained findings demonstrated that the failure of outlet pigtails was attributed to over-design operating temperatures. Under operation at high temperature, the pigtails undergo the advance stage of irreversible creep and failed before their designing life span.

1. Introduction

The steam-methane reformer (SMR) furnaces are widely used in the petrochemical industry for production of synthesis gas in ammonia and methanol plants [1]. The process is accomplished by reforming mixtures of C1 to C4 hydrocarbon gases plus steam in the presence of nickel-based catalyst. As a result, natural gas and steam are converted into hydrogen, carbon dioxide and carbon monoxide. The overall process is highly endothermic and requires the input of large amounts of heat to keep the reaction rates high enough [2,3]. The process gas temperature required at the outlet of the catalyst-filled tubes is in the range of 750–900 °C at the pressure of 35–40 kg/cm^2 [4]. The furnace consists of vertical catalyst-filled alloy tubes, supported in a rectangular refractory-lined combustion chamber which is heated by burners [5]. Tubular reformers are designed with a variety of tube and burner arrangements in the furnace. The four most commonly used arrangements are bottom fired, top fired, side fired and terrace wall reformers [5,6]. Reformer tubes made of INCOLOY 800 HT alloy are generally designed to withstand combination of severe conditions of high temperature, pressure and corrosive atmosphere for an operational life of 100,000 h. The reformer tubes are supported at the bottom of the furnace, and a tensioning device is used at the top to take up the expansion of hot tubes. The tubes are connected to sub-headers at the inlet and outlet by small bore pipes (Fig. 1) known as pigtails [7]. Pigtails are used in a flexible connection, serving to accommodate some of the considerable thermal expansion which occurs between cold and hot temperatures. These components are made of high Cr–Ni alloy tubes and carry the reformed gas from the catalyst tubes to collection headers [8]. Special alloys are used for tubes, outlet pigtails and outlet headers, which are subjected to high temperatures, pressures and corrosive atmosphere [9].

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During service, depending upon the operating conditions, several mechanisms such as creep, fatigue, corrosion and oxidation become operative. Accumulation of microstructural damages in the components due to prolong operation decreases their load bearing capacity thereby limiting the lives of the components [10].

Inevitably, the service life of components such as the reformer tubes and process gas manifold is limited. Hence, pigtail damage is an industry-wide problem and their failure is a common cause of production loss, plant down-time and potential risk to plant personnel [11]. Numerous research investigations have been carried out to optimize the microstructures and mechanical properties of the alloys used for steam reformer tubes [10–12]. However, prior published investigations regarding damage in pigtail tubes are limited. Roumeau found the failure was attributed to creep deformation which was accelerated due to the fine grain size of the material at the bends because of poor cold working of the tubes [13]. Kodali and Ritchert attributed the failure to a combination of creep damage and high-temperature oxidation [14]. Monteiro discussed the failure due to service at high temperature as a result of cracking caused by interconnection of voids at grain boundaries and that the curved parts were in a more advanced stage of creep compared to the straight parts [15]. Gommans et al. showed that the cracks in the bottom manifold of a steam reformer were due to strain-assisted inter granular oxidation, which was strongly influenced by grain size. It is also found that creep limited by grain-boundary diffusion was the acting deformation mechanism for INCOLOY 800 H at 800 °C and low stresses [16]. Xu et al. investigated the failure of an INCOLOY 800 HT pipe operating at 1032 °C. They determined that the failure was not caused by creep but from high operating stresses exceeding the yield strength of the material. A creep remaining life assessment of an INCOLOY 800 H material was performed by Maharaj et al. by determining the percentage creep cavities versus the tube outer diameter [17]. A good correlation was achieved by fitting the data points to the classic creep strain versus time curve. Recently, Daga and Samal presented a real time monitoring system of operating parameters for high temperature components, including inlet pigtails, used for the calculation of the materials remaining life fraction [16–18]. Spyrou et al. developed a finite element model to evaluate the creep behavior of INCOLOY 800 HT pigtails in a refinery steam reformer under various operating conditions after 8.5 years of operation. Their findings indicated that the most important parameters affecting the structural behavior of pigtails are the operating temperature, reduction of thickness, magnitude of counterweights and grain size of the alloy. The recommended grain size for INCOLOY 800 HT is ASTM No 5. [18–20].

1.1. Plant description

The ammonia plant in Shiraz Petrochemical Complex has been designed to produce 1200 MTD of liquid ammonia from natural gas via the relatively standard processes of steam reforming and synthesis gas generation by CO conversion, CO_2 removal and methanation. The primary reformer of the plant is a standard top-fired Humphreys and Glasgow (H&G) designed radiant box [3]. Fig. 2 is a schematic front view of the primary steam reformer. The primary reformer in the plant is a furnace containing 352 catalyst tubes arranged in eight radiant chambers of 44 tubes each. The catalyst tubes are vertically installed and supported by concrete counterweights. The feed gas, consisting of natural gas and steam, enters from the top end at a temperature of 365 °C and pressure of 35 kg/cm^2 and flows down through the catalyst in individual tubes before coming out at a temperature of 780 °C and a pressure of 30.5 kg/cm^2. Heat is provided by firing of 117 burners which arranged in nine rows and firing downwards. The heat is transferred

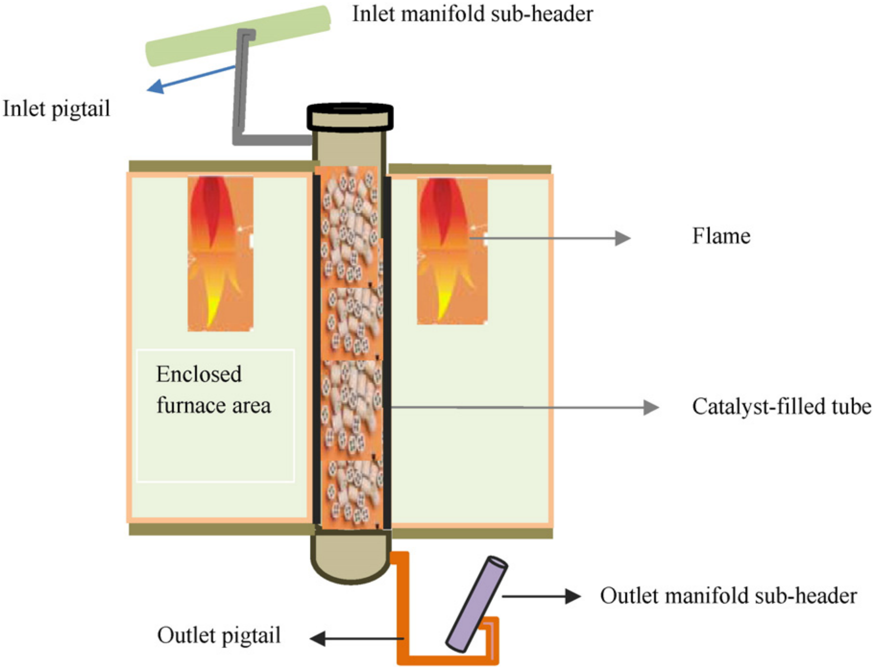

Fig. 1. A schematic diagram of the tube/pigtail assembly.