CARBONACEOUS DEPOSIT FORMATION FROM JET FUEL AND NORPAR-13

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Introduction

Increasing fuel temperatures in jet engines can cause severe fouling problems because of carbonaceous deposit formation in heat exchangers, fuel nozzles, and fuel lines. In advanced engines of future aircraft the fuel may be heated up to temperatures as high as 540 °C prior to combustion [1]. At high temperatures (>350°C), the fuel undergoes thermal decomposition (pyrolysis), which leads to different kinds of solid deposits [2]. It has shown that deposits can be produced by both gas-phase (pyrolytic carbon) and liquid-phase reactions (carbonaceous mesophase) in afterburner fuel lines of an aircraft [3]. The interaction of reactive hydrocarbon gases with metal surfaces at elevated temperatures is also of concern [4].

The objective of this work was to study the effects of different surfaces on deposit formation from pyrolysis of a Jet A fuel and a mixture of C11-C15 n-alkanes (Norpar-13).

Experimental

A flow reactor, was used to heat the fuel samples up to 550 °C in the presence of different surfaces. The fuel in the tank was sparged with either air or nitrogen, and the reactor was sparged with nitrogen prior to each test. The air saturated fuel contains approximately 70 ppm O2 by weight [1,5].

In addition to 304 stainless steel, silica coated stainless steel tubes, Silcosteel, (Restek Corporation, Bellefonte, PA) were used with two different coating thickness of approximately 450Å and 1000Å without any deactivation layer (phenyl or methyl groups) present in the coating.

The metal foils inserted in the reactor are nickel (99.9%), and different types of stainless steel , 304 (Fe / Cr 18 / Ni 10), and 321 (Fe / Cr 18 / Ni 8 / Ti), all supplied by Goodfellow Co., UK. All the foils were 0.05 mm thick. Samples of foils were cut into 3 mm wide and 50 mm long coupons which were cleaned with acetone in an ultrasonic bath before reactions.

A SEM and a field emission scanning electron microscope (FESEM) (JEOL JSM6300F) was used to examine the deposit morphology on metal surfaces.

Results and Discussion

Figure 1 compares the deposition profiles from Norpar-13 under air and nitrogen saturation. Approximately 2.5 times more deposits were produced with nitrogen than that obtained with air saturation. These results are interesting because it is generally believed that the presence of oxygen during thermal stressing promotes solid formation.

The FESEM micrographs of the deposits from nitrogen-saturated Norpar-13 showed that they are made up of filamentous carbon. Using energy dispersive spectroscopy (EDS), the tip of the filament showed a large iron peak, indicating that metal particles, consisting mostly of iron, were lifted from the stainless steel surface and were incorporated in the filaments. The catalytic activity of transition metal surfaces such as iron and nickel to form filaments of various morphologies has been studied extensively [6,7]. The presence of carbon filaments in the deposits suggests that a similar mechanism takes place during thermal decomposition of Norpar-13 under drastically different conditions compared to those usually associated with the formation of filamentous carbon (e.g., low pressure, high temperature, high hydrogen/hydrocarbon ratio) [7]. Excessive formation of filamentous carbon, or removal of metal particles from the surface may also create problems with degradation of thin-walled fuel lines in the long term.

The lower deposit yields obtained under air saturation from Norpar-13 can be attributed to the passivation of some surface sites by oxygen. Microscopic examination of tube surfaces which have seen high temperatures showed, in fact, that tubes used under air saturation conditions contains much less filamentous carbon than those under nitrogen saturation.

Figure 2 compares the temperature and deposition profiles from stressing Norpar-13 under nitrogen saturation in a 304 stainless steel tube and two silica coated tubes (SilcoSteel) with different coating thickness, 450 Å and 1,000 Å. Compared to a bare 304 stainless steel surface, the 450 Å thick coating lowered the amount high-temperature deposits from Norpar-13 by a factor of three. The 1,000 Å thick coating, however, virtually eliminated the filamentous carbon formation. under both nitrogen and air saturation. The fused silica layer, however, showed deformation under stressing with air saturated Norpar-13 which may result from the reaction of oxygen with the coating

The SEM micrograph of the deposit on the nickel coupon shows that it consists of fibrous structures which appear to be filaments covered with pyrolytic carbon. Nickel particles can still be seen, however, at the tip of the fibers. It is possible that the pyrolytic carbon deposition on the filaments led to a rapid deactivation of the metal particle tip and resulted in the formation of short and thick fibers.

An SEM analysis of the deposits collected on stainless steel 304 and 321 coupons show that these deposits are also filamentous carbons. The morphologies of the filaments on the two coupons are, however, different from each other, and more deposit has been formed on 304 than on 321 stainless steel surface. The filaments on 304 are longer and they appear to be more rigid and better developed. The EDS analysis indicates that the tip of the filaments consists of Fe, Ni, and Cr, with an enriched Fe peak.

Deposits formed from Jet A fuel look very different from those deposited from Norpar-13. The deposited surface looks rougher and solid deposits are easily peeled off from the 304 stainless steel tube surfaces. Figure 8 shows the FESEM micrographs of the deposits produced from the Jet A fuel on the stainless steel tube. SEM micrographs show that the deposits consist mostly of platelets as opposed to filaments found in Norpar-13 deposits. The formation of graphitic carbon from light hydrocarbon decomposition on nickel surfaces has been reported, but at substantially higher temperatures [8]. The particles gave a large sulfur peak in the EDS analysis, suggesting that sulfur compounds were incorporated in the deposit structure.

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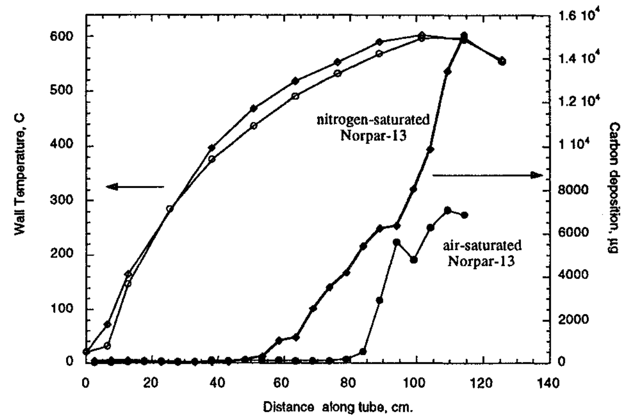

Figure 1. Temperature and carbon deposition profiles on 304 stainless steel tubes.

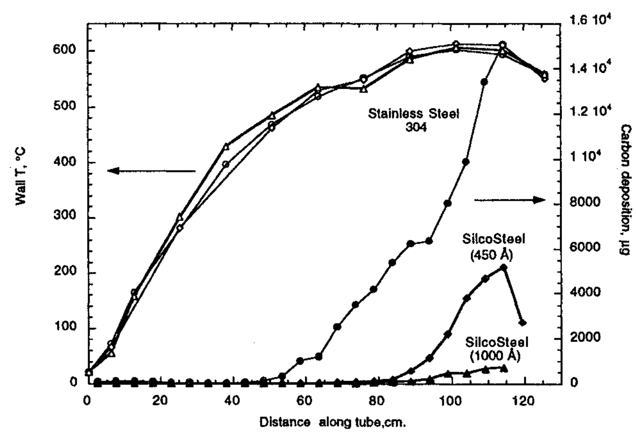

Figure 2. Temperature and carbon deposition profiles on 304 stainless steel and Silcosteel tubes.