

Evaluating the Induction System Deposit Tendencies: Bench Technique

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ABSTRACT

The purpose of this work is to describe a technique that is capable of determining the induction system deposits (ISD) tendencies of gasoline, applying the ISD apparatus developed at Southwest Research Institute (SwRI®). The results showed that temperature, fuel quality, and presence or absence of lubricant oil in the sample affect the quantity and the characteristic of the deposits. Engine tests, done in a Fiat 1.4 tetra fuel engine, were carried out in order to verify the intake valve deposits (IVDs). Another bench technique, the Intake Valve Deposits Apparatus (IVDA) proposed by SwRI®, was also evaluated. It was observed that the results obtained with ISD have qualitative similarity with the trend observed for the results in the engine and in the IVDA tests. So, it can be concluded that bench-scale tests are a promising alternative to make a first screening of the gasoline samples prior to the engine tests.

INTRODUCTION

In recent years, there has been a growing concern about the reduction of fuel consumption as well as gas emissions to the environment, allied with the increase of the engine's specific power. There is a joint effort to achieve improvements in engine performance, which have considerable impact on the environment. In this context, the IVDs can be a problem for the proper operation of the engine, especially with the growing innovation in devices designed to improve performance and reduce emissions from vehicles, whose tolerance for residues is decreasing.

Several researchers reported by Toyota verified that deposit formation is greatly influenced by valve temperature and the presence of lubricant oil. Nomura et al. [1] used an IVD bench test to show that an increase in the oil leakage rate, at a constant valve temperature, increases the amount of deposits.

The quality of this oil also affects deposit formation. The authors concluded that deposit formation was significant in the temperature range of about 200-350°C. Esaki et al. [2] did chemical analyses of the deposits and indicated that it was mainly composed of oxidized and pre-carbonized products of engine oil. In a further work, Ohsawa et al. [3] showed that the maximum deposit formation occurred at a valve temperature of 160°C working just with gasoline, and 250°C if it's used only with oil in the test. Therefore, these results depend on the real engine conditions.

SwRI® has developed two bench techniques to evaluate the tendency of motor gasoline in the formation of induction system deposits. These compact analytical tools are known as the Induction System Deposit (ISD) and IVDA, and simulate conditions in spark-ignition engines that cause deleterious deposits on hot metal surfaces such as the intake valve. Johnston and Dimitroff [4], from SwRI®, described the development of the ISD apparatus. They reported that this apparatus requires a minimum fuel sample and uses a retainable metal tube as the deposit collecting surface. In a further work, Johnston and Stavinocha [5] obtained ISD repeatability, and they suggested that deposit formation occurs as the combined result of thin film flash evaporation and oxidation.

In order to evaluate the deposit formation tendency of isolated fractions from Venezuelan gasoline, Martin [6], in a series of papers, tested these samples in an ISD apparatus. It was observed that the chemical reaction between benzothiophenes and benzothiophene oxides, forming high molecular weight sulphur compounds, is the principal reaction that takes place in the deposit formation processes. Also, it was noticed that the temperature has an important role in deposit formation.

For more information Kalghatgi [7] presents a literature review about deposits in gasoline engines. In that work the nature and formation of the deposits, effects of deposits on engine operation, how to control the deposits, and test procedures used in deposit-related studies were explained. The target of this paper is to investigate the fuel deposit forming tendencies applying the ISD technique. In the research, both IVDA and motor tests were used.

TEST PROCEDURE

The ISD bench test

During ISD tests, a measured amount of fuel (100 ml) is metered from a reservoir to a spray nozzle, mixed with air, and expelled on a heated aluminum tube. This tube, named deposit tube, is weighed before and after the test to determine the weight of the deposits. The increased weight associated with the deposit is the ISD index, reported in mg/100 ml. A water cooling jacket is used to prevent fuel vaporization within the spray nozzle to avoid erratic flow. The deposit tube has an interior heating rod that provides heat transfer through the deposit tube wall. A thermocouple drilled within this tube wall provides an accurate means of measuring the deposition surface temperature. The thermocouple is in the deposit tube wall facing the spray. Deposit tube and spray nozzle temperatures are displayed in digital readouts throughout the test. Testing of each 100 ml sample takes approximately one hour: 50 minutes for spraying the test fuel onto the deposit tube, followed by 10 minute heat soak and cooling time. The repeatability supplied by SwRI® is: 0.1 mg/100ml for results of 0 to 1.5 mg/100ml, 0.2 mg/100ml for results of 1.5 to 3.0 mg/100ml, and 10% relative for results >3.0 mg/100ml [5]. [Figure 1](#) shows the structure of the ISD test. For a complete operating procedure see Federal Test Method 500.1 [8].

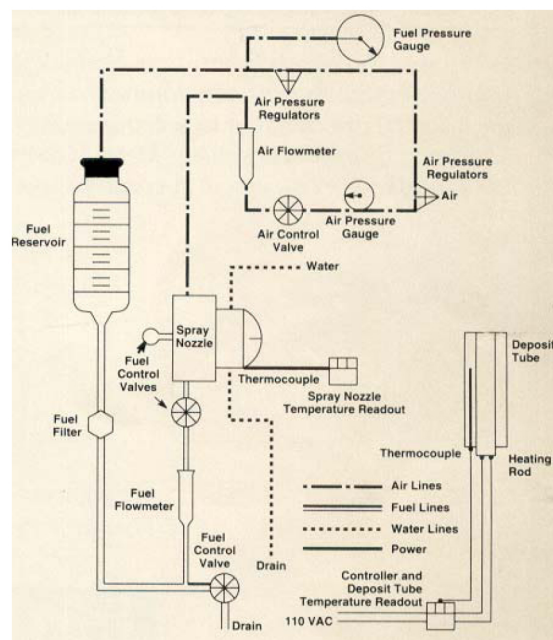


Figure 1. Schematic figure of ISD apparatus provided by SwRI®.

The IVDA bench test: keep clean procedure

In the IVDA test, the intake air is directed through a heat exchanger that is maintained at 205 °C. Total test cycle duration is 20 hours and requires 2 liters of sample for one test. This test cycle needs plus 4 hours for sample preparation and cleaning. Lacey et al [9] indicated that IVDA presents a good correlation with the BMW vehicle test (ASTM D5500) and Ford 2.31. motor test (ASTM D6201). [Figure 2](#) shows the structure of the IVDA test.

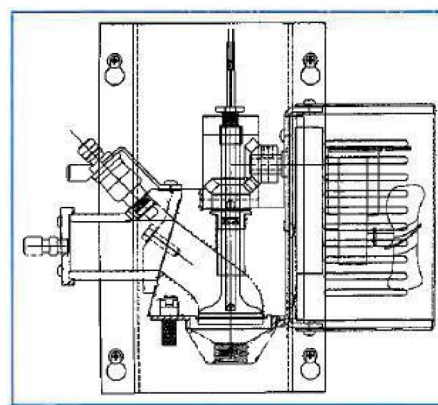


Figure 2. Schematic figure of the IVDA provided by SwRI®.

The motor test

Petrobras' Research Center (CENPES) developed a motor test to evaluate IVDs [10]. The test is performed in a Fiat 1.4 liter tetra fuel engine, as originally assembled in the vehicle, which can run with ethanol-free gasoline, any proportion of ethanol-blend gasoline, hydrated ethanol and natural gas. The test comprises a 100-hour run with 12 minute cycles. Each cycle consists of 2 steps: the first at 1000 rpm and 24 Nm load for 4 minutes and the second at 2200 rpm and 60 Nm load for 8 minutes. When the test finishes, the intake valves are weighed and visually inspected.

RESULTS

The influence of parameters such as gasoline quality, temperature, or lubricant oil presence was tested using the ISD apparatus.

In order to clarify the effect of lubricant oil presence, a Phillips's injector fouling fuel used in the Port Fuel Injection test (ASTM D6421 [11]), known to provide a high deposit level, was analyzed.

Also, the temperature effect on deposit formation was examined.

The tests were done with pure gasoline and gasoline with lubricant oil. It can be seen from Table I and II that deposit formation from gasoline were maximized at a temperature of approximately 170 °C, and deposit formed from gasoline with lubricant oil were maximized at approximately 250 °C.

Figure 3 illustrates the results obtained in this step. These photos indicate that deposits formed with fuel plus oil at high temperature were dry and heavy (c). Nevertheless, at 150° C, the deposit formed over the deposit tube was a viscous fluid washed by n-heptane (a and b). So, in this case the deposit tube was kept clean. Comparing Fig. 3 (c) and (d), if only a small amount of lubricant gets into the intake system, it can mask the fuel effect on intake valve deposits.

Previous studies provided contradictory evidence about lubricant oil importance in IVD formation. Cheng [12] showed that high boiling base oils kept the valve clean by forming a protective layer, while low boiling base oils increased the deposit level. Moreover, the presence of oil differs with engine operating conditions and oil leakage is inevitable in a real engine.

For further tests, to reduce the oil influence in the ISD results, it was decided not to add oil in the fuel to be analyzed in ISD apparatus tests. Moreover, for gasoline samples without lubricant oil, it was decided to work at the temperature indicated by SwRI® and Federal Test Method 500.1. (T = 190 °C) [4] [8].

Table I. Temperature effect for ISD test; with lubricant oil 0,15%v/v; fuel: Phillips gasoline.

T (°C)	150	190	200	250	280
Deposit (mg/100ml)	0	0	0.6	3.5	2.6

Table II. Temperature effect for ISD test; without lubricant oil; fuel: Phillips gasoline.

T (°C)	150	170	190	210	230
Deposit (mg/100ml)	1.8	2.6	2.1	1.4	0.6

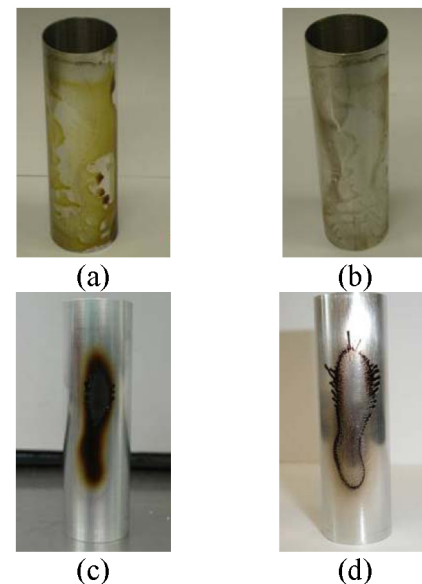


Figure 3. Deposits (ISD) for T=150 °C, with lubricant oil, before washed with n-heptane, (a) and after washed (b); T=280 °C with lubricant (c); and T=190 °C without lubricant (d).

The next attempt was made to ensure the influence of gasoline composition on deposit formation. For this, n-heptane, considered a low-deposit stream, was mixed in different proportions with a Phillips gasoline (provided from another batch than the one used for previous tests). Table III summarizes the results obtained in this step with the ISD apparatus working at 190°C (as suggested by the SwRI® procedure). As expected, increasing the n-heptane portion in the final mixture gives a significant reduction in the deposit weight.