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Discussion

P. T. SULZER.⁷ Just as in the case of the investigations made by Bruce O. Buckland and Donald G. Sanders, we also have found, in many test rigs and in practical tests on the semiclosed 20,000-kw gas-turbine plant of the NOK at Weinfeld, that the presence of sodium compounds in residual fuels favors the formation of oil-ash deposits.

Our tests were carried out with heavy oils, containing normally about 500 ppm ash, 200 ppm V_2O_5 , and 100 to 200 ppm Na_2O . Former test runs in the Weinfeld plant showed that the adoption of such a fuel leads to serious trouble because of the formation of deposits. The residual oil, as an experiment, was then treated in a manner analogous to that which has long been customary in diesel-engine plants working with heavy oils (washing with steam and centrifuging). The Na_2O content of the fuel could be reduced to about 10 ppm. A subsequent trial run with the plant for about 100 hr showed a greatly reduced formation of deposits, but considerably more corrosion. The mean temperature at the turbine inlet was 650 C.

A more accurate investigation gave the following results: Because of the deposits formed when burning the nontreated fuel (deposits consisting for the most part of Na_2SO_4 , Fe_2O_3 , and V_2O_5), the blade material is protected to a certain extent; the diffusion flow of oxygen to the metal is checked by the layers. After the sodium compounds had been washed out, the remaining V_2O_5 together with the remainder of the ash components (mainly iron and traces of calcium and silicon) formed only badly adhering deposits, which continually fell off.⁸ This phenomenon appears to us to explain the considerably stronger corrosive properties of a fuel with high vanadium content and few sodium components.

Removal of the sodium components from a fuel with high

vanadium content is desirable in cases where additives are introduced into the fuel during the washing process or after it. According to our tests, however, the addition of magnesium compounds caused heavy deposits, especially at high pressures (20 atm abs). Possibly this phenomenon has some connection with the simultaneous presence of sodium compounds. Further, the greater formation of SO_3 at a high pressure should favor the formation of $MgSO_4$ deposits. Systematic tests are being carried out regarding the formation of $MgSO_4$ deposits in dependence on pressure, temperature, and Mg content of the fuel.

According to our experience, it might be of interest to add barium compounds to the fuel. Barium additives are also cheap and act similarly to magnesium, but form only minor deposits even at a high pressure.

As we have stated already, the admixing of kaolin to the fuel in fairly large amounts (5 to 10 times the amount of ash) gave the most favorable results. The introduction of traces of metallic dusts, for instance, aluminum powder (about 1 to 2 per cent of the amount of kaolin) reduced the formation of deposits in the combustion chamber and in the tubes of the air heater, which is situated between the combustion chamber and the high-pressure turbine. The gas temperature when entering the turbine is about 1050 C.

It may be assumed that the necessary amount of additive (kaolin) could be considerably reduced when using a fuel from which the sodium previously has been removed.

AUTHORS' CLOSURE

The authors are pleased to know that Mr. Sulzer, in his plant tests, also finds that washing the sodium out of the fuel reduces the deposit. We are particularly interested to hear that this sodium reduction in his case also increases the corrosion because we can predict this to happen from our crucible and small-burner tests. His fuel, unwashed, has a sodium to vanadium ratio of about 1.0 and when it is washed, this ratio is about 0.07. From Fig. 25 of the paper describing the crucible tests,⁴ it can be estimated that the corrosion might be expected to increase by a factor of 3 or 4 to 1 when going from a sodium to vanadium ratio of 1.0 to 0.07 at 1300 F. This, of course, is for an ash composed entirely of sodium sulphate and vanadium pentoxide and for a 25 Cr-20 Ni steel exposed for only 20 hr.

From Fig. 12 of the present paper the same result might be predicted. This figure shows the small-burner-test results for 100 hr and at 1600 F on 25 Cr-20 Ni specimens. An oil having 159 ppm of vanadium and 243 ppm of sodium was tested both unwashed and washed. Unwashed, the sodium-vanadium ratio was 1.63 and, washed, it was 0.04. This change produced a twelfold increase in corrosion.

Mr. Sulzer's explanation that the layers of sodium sulphate reduce the corrosion by preventing the diffusion of oxygen to the steel seems to us not to be borne out by our tests. In the crucible the specimen is entirely surrounded by the synthetic ash and the portion thus surrounded corrodes. Furthermore, even when the oxygen is thus excluded, a substantial increase in corrosion occurs on reducing the sodium as described. In any case, the reduction in corrosion due to the vanadium pentoxide produced by having a high ratio of sodium to vanadium is not sufficient to be useful for gas turbines, especially when the metal temperatures are 1300 F or more. Additives to prevent the vanadium type of corrosion are sufficient, however, as shown by both Mr. Sulzer and ourselves.

In this case, though, it is desirable even from a corrosion standpoint alone, and if the deposit features are ignored, to have a low ratio of sodium to vanadium. It is not given in the paper, but evidence is at hand which shows that, when the vanadium is inhibited by additives such as, say, magnesium, a sodium-sulphate type of attack can occur if the sodium to vanadium ratio is

⁷ Sulzer Brothers, Ltd., Winterthur, Switzerland.

⁸ These tests are fully described in a paper by J. G. Bowen, London, England, and P. T. Sulzer, Winterthur, Switzerland, read in 1955 at a Gas-Turbine Meeting of the ASME.

too high. Our small-burner tests show that with ratios of sodium to vanadium of $\frac{1}{2}$ or more, a 25 Cr-20 Ni specimen shows substantial sulphide attack in 600 hr with temperatures as low as 1400 F.

Barium compounds, as Mr. Sulzer suggests, have shown good ability to inhibit vanadium-pentoxide attack in our crucible tests. In the single small-burner test we ran they did not show as much promise as magnesium. Perhaps, this one test is not too conclusive and we should do further work with this additive.

As Mr. Sulzer has found, we, too, have found that aluminum and silicon are excellent in preventing deposit. In addition, in

a small burner test with aluminum and silicon added in large quantities as oil-soluble compounds, a substantial reduction in corrosion of a relatively high vanadium oil was observed. We have not yet developed a means of introducing these materials in their solid and inexpensive form, however, in a manner that results in an acceptable maintenance of the fuel pumps, fuel nozzles, and other fuel-handling equipment.

This failure caused us to abandon the plant-scale tests which were started using an aluminum-oxide additive and to turn to the use of a water-soluble material which could be emulsified easily with the fuel.