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THERMAL OXIDATION TESTER HEATER TUBE DEPOSIT EVALUATOR AND METHOD OF USING

Malcolm G. Townsley, Park Ridge, Ill., assignor to Erdco Engineering Corporation, Addison, Ill.
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ABSTRACT OF THE DISCLOSURE

A chopped light beam is divided into a measuring beam and a reference beam. The measuring beam is impinged on a thermal oxidation tester heater tube. After integration of the light reflected from the tube, an electrical signal representative of the intensity of that light is developed and compared with an electrical signal generated from the reference beam. Due to the chopping of the light these are alternating current signals. Initially, the point of impingement on the tube is a clean area and the output indication of the electrical signals is established at zero. Thereafter, a condition of no reflection is established and the output indication is established at a maximum. Thereafter, the point of impingement is established at an area on the tube having a deposit. The output indication reflects the extent to which the reflected light is diminished by the presence of the deposit.

BACKGROUND AND SUMMARY OF THE INVENTION

In jet aircraft engines it is a standard practice to use the fuel flowing to the engine as a coolant in a heat exchanger. The heat exchanger is relatively hot resulting in a tendency for the fuel to break down and deposit carbonaceous material on the heated surfaces. These deposits can build up and thereby degrade the heat transfer characteristics of the heat exchanger to a degree such that the engine must be taken out of service and the heat exchanger cleaned. The degradation of the heat exchanger is affected by the thickness of the deposit and also by the physical density of the deposit. Jet engine fuels will vary as to their tendency to break down and leave a carbonaceous deposit on a heated surface. In deciding on a particular purchase, the prospective purchaser of the fuel wishes to know the degree to which a particular fuel offered to him has such a tendency to break down and leave a deposit. As a consequence, thermal oxidation stability tests have been developed for use in measuring the characteristics of aircraft engine fuels in this respect. There are other applications for similarly testing fluid hydrocarbons. For example, a refinery may want to know the tendency of a particular feed stock to leave a carbonaceous deposit when it is being heated in connection with a distillation or cracking process.

The present standard tests are defined by the American Society for Testing Materials (ASTM) as No. D1661. In this process a thermal oxidation test heater tube (herein called T.O.T. heater tube) is used which is a polished aluminum cylinder having an electric cartridge heater in the interior. It is thereby heated to a specified temperature and while hot has the jet fuel or oil flow over it for a specified period of time. During this time a carbonaceous deposit will build up on the heated portions of the exterior of the cylinder. The maximum thickness of the deposit is used as a measure of the tendency of the fuel to break down in service and leave deposits on the engine heat exchanger. Also, by taking readings at different temperatures further information can be obtained as to the temperature breakdown characteristics of

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the fuel. The present practice is to run a total of five different tests. These deposits are, in general, straw to brown in color and grow deeper in color and redder as the severity of the deposit increases; however, some deposits are blue, green, white or peacock.

The present procedure for measuring the deposit is for an individual to visually compare the deposit on the tube with ASTM color standard chips. These chips are flat pieces of aluminum coated with dyes to give particular color appearances. There are various chips having a graduated series of appearances purporting to represent the appearance of tubes having various degrees of deposits thereon. The individual performing the test will visually compare the heater tube having the deposit developed thereon with the color chips until, in his opinion, a particular chip matches the appearance of the deposit on the tube. The fuel that was tested is then rated as being of the standard established by that particular color chip. It turns out that this is a very crude way of measuring the degree of the deposit. It is not uncommon for two experienced testers to so examine a particular coated heater tube and select different chips which, in their opinion, correspond to the appearance of the deposit on the tube. There are various factors which contribute to this problem such as the fact that the chips are on a flat plate while the tube surface is curved; the chips are colored with dyes while the tubes are colored with carbonaceous deposits derived from the breaking down of the fuel being tested; the fact that there are varying colors involved and individuals will not necessarily observe the same fine distinctions between particular shades of colors (i.e. many individuals have minor color blindness in varying degrees and characteristics); etc.

The present invention has for its principal object and advantage the providing of an apparatus for measuring the relative extent of deposit on a T.O.T. heater tube and eliminating the disadvantages with the present system of comparing the tube with color chips. This invention is predicated upon the discovery that color is a relatively unimportant factor in the extent of the deposit on the heater tube. Prediction of the time required to build up an objectionable deposit in the heat exchanger can be based on the mass of material per unit area which is deposited on the heater tube during the testing period. The mass per unit area of an absorbing material is nearly linearly related to the optical density of the deposit, where the optical density is equal to logarithm $1/(1 - \text{percent absorption})$. To put it another way, the extent to which the material on the tube will absorb light (thus appear dark) is relatively linearly related to the thickness of the deposit, regardless of the wave length of the light shining on the tube (within the range involved in such tests). Thus, for all practical purposes, it is possible to ignore the color factor which had previously been considered to be rather important in measuring the degree of the deposit. Also, I have found that within the range of deposits that are involved, there is no appreciable reflectance of light from the deposited material itself. These led me to make the measurement on the basis of the extent to which a light beam is absorbed by the deposit on the tube, as measured by the optical density of the deposit.

Another discovery that is important in connection with the present invention is that the diffusivity of light impinged on the tube deposits varies from fuel to fuel without an apparent correlation with the density of the deposit. This discovery dictated to me the necessity of integrating the light reflected from the tube rather than attempting to use specular reflection or picking up the nonspecular (diffuse) reflection from the tube in a particular direction with respect to the tube and light im-

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pingement thereon, so that it is the diffuse optical density which should be measured.

Another object and advantage of the present invention is related to the ease and accuracy with which calibration may be obtained and maintained. I have discovered that the total reflection from the bare heater tube (each being a polished aluminum surface) varies from tube to tube. Therefore, this must be taken into account in obtaining accuracy of measurement. My invention permits, with little difficulty, the apparatus to be calibrated to the particular tube on which measurements of the degree of deposit are to be made.

Along the same line, the readout indication, e.g. meter, can readily be calibrated with a set of calibrated absorption filters (calibrated to the standards of the U.S. Bureau of Standards). Thus, to the extent that the measuring beam of light is absorbed by the deposit on the tube, the exact degree of that absorption can be related to an existing measurement range.

Further objects and advantages of the invention will be apparent from the following description of a specific embodiment.

The present invention relates to a method and apparatus for accurately and easily determining the thickness of carbonaceous deposit on a T.O.T. heater tube, as measured by the optical density of the deposit.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a section through an embodiment of the invention, in somewhat diagrammatic form;

FIG. 2 is a section taken at line 2—2 of FIG. 1; and

FIG. 3 is a diagrammatic illustration of the electrical circuitry employed in connection with the embodiment of FIG. 1.

DESCRIPTION OF SPECIFIC EMBODIMENT

The following disclosure is offered for public dissemination in return for the grant of a patent. Although it is detailed to ensure adequacy and aid understanding, this is not intended to prejudice that purpose of a patent which is to cover each new inventive concept therein no matter how others may later disguise it by variations in form or additions or further improvements. The claims at the end hereof are intended as the chief aid toward this purpose, as it is these that meet the requirement of pointing out the parts, improvements, or combination in which the inventive concepts are found.

Referring to FIGS. 1 and 2, a light source 10 produces a beam of light. A lens 11 projects this beam through the entrance opening 12 of an integrating cavity 13 and displays the beam across the end wall 14 of the cavity. The interior of the integrating cavity 13 is white and, in effect, the cavity serves as a source of pulsed (as subsequently described) light.

A passage 16 forming a window extends outwardly from the integrating cavity 13 to a chamber 17 and defines what will be referred to as a "reference" beam of light. A slide 18 fills chamber 17 in the cross-sectional dimension and is longitudinally movable in chamber 17. This slide carries a photocell 19 for producing an electrical signal which is a function of the magnitude of the reference beam as received by the photocell. By moving the slide 18, and thus photocell 19, toward or away from passage 16, the amount of light reaching the photocell from the integrating cavity 13 can be varied. A second passage 20 communicates with integrating cavity 13 and leads to a photocell 21. For convenience of illustration, passages 16 and 20 have been shown directly opposite each other, but such an arrangement is not likely to be used in a specific embodiment. As a matter of fact, photocell 21 does not necessarily have to communicate with integrating cavity 13, since its only purpose is to

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pick off the occurrence of chopping of the light beam as hereinafter described.

End wall 14 of cavity 13 has an opening or window 23 therein. This forms a bright spot of light which is picked up by lens 24 and imaged (or impinged) at a point 25 on the surface of T.O.T. heater tube 26. This is referred to as the "measuring" light beam. Between lens 24 and opening 23 is a transverse slot 27 of a size to receive a slide 28 bearing a standard density filter 29. Actually, a whole series of such filters of varying densities are employed, but only one is illustrated.

An integrating light sphere 31 is employed. It has a slot 32 of a size to receive a portion of heater tube 26. In one wall of the sphere is a photocell 33 to produce an electrical signal indicative of the extent of illumination of the interior of the sphere. A screen or shade 34 is positioned in a direct line between photocell 33 and point 25 so that no light will move from point 25 directly to the photocell.

A motor 36 rotates a chopper blade 37 mounted on the shaft 38 of the motor. As seen in FIG. 2, the chopper blade comprises a plurality of solid segments 39 separated by openings 40. As the solid segments 39 move across the light beam and in front of opening 12 the light is cut off, and then re-established when the openings 40 move across the line of the light beam. Due to the chopping, the light is continuously going on and off in integrating cavity 13. Thus, the various photocells will generate electrical signals in square wave fashion, the magnitude of the square waves being a function of the amount of light received by the respective photocells.

The square wave signals from photocells 19 and 33 are sent respectively to preamplifiers 45 and 46. After the amplification in the preamplifiers, the two square wave signals are delivered to differential amplifier 47. The output of the differential amplifier is a square wave which has a magnitude representing the difference in magnitude of the two input signals from the preamplifiers 45 and 46. This square wave difference signal is then sent to a filter and amplifier 48. The filter is a band pass filter tuned to the chopping frequency of the light beam (i.e. the rate of interruption of the beam by chopper blade 37). This filtering is for the purpose of eliminating extraneous noise components in the electrical signal.

The output of the filter and amplifier 48 is a smooth sine wave, again having a magnitude representing the difference in magnitude of the two square waves supplied to the differential amplifier 47. This signal is further amplified in a final amplifier 49 having a gain control 50 by which the magnitude of the sine wave signal delivered to the synchronous rectifier 51 may be controlled. The synchronous rectifier is controlled by a square wave signal from amplifier 52, which in turn is fed by photocell 21. This square wave signal is thus synchronized with the chopping of the light beam by the chopper 37. It causes the synchronous rectifier 51 to pass only one-half of the input signal from final amplifier 49 in synchronism with the rotation of the chopper blade 37.

The rectified output signal is delivered to an indicator such as meter 53. The indicator could be a moving strip chart or the like on which a graph of the magnitude of the output signals was indicated. The meter is calibrated so that when the output of photocell 33 is substantially negligible the meter reads 100 (representing total absorption of the measuring beam), and when the outputs of the photocells 19 and 33 are identical in magnitude (for all practical purposes), the meter reads zero. Intermediate calibrations can be obtained by using various density filters 29, which are inserted across the light beam (through opening 27) to cut down on the amount of light appearing at point 25 on the tube 26.

The electrical circuitry of FIG. 3 was known prior to the present invention, but not with the combination of components with which it is employed in the present invention.

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OPERATION

A carbonaceous deposit would be developed on heater tube 26 in the same manner in which it is presently being done in the art. Since only part of the tube is heated to its maximum temperature, while other parts of the tube are substantially cooler during the operation of developing a deposit on the tube, those other parts of the tube will not have developed a deposit thereon. The carbonaceous deposit develops only on the surfaces of the tube that are highly heated. This fact is employed in the calibration of the apparatus.

Initially, a portion of the tube having no deposit thereon is positioned at point 25. This will result in the maximum reflection of light for that particular tube. By lens 24 the light beam is specularly impinged at point 25, but all of the light, both specular and diffuse, reflected by the tube is integrated by the sphere 31 to produce an illumination in the interior of the sphere, which illumination is thus commensurate with the magnitude of the sum of the specular and diffuse reflections. Since point 25 is free of deposit, the electrical output of photocell 33 is thus at a maximum for that particular tube. An adjustment then is made so that the electrical signal from photocell 39 is equal in magnitude to the signal from photocell 33. This could be done electrically, but in the illustrated embodiment it is done by moving photocell 19 toward or away from passage 16 to increase or decrease respectively the magnitude of its output signal. With the output signals of the photocells 19 and 33 being equal, the output of differential amplifier 47 is zero, and the reading of meter 53 will be zero (representing the condition of no absorption of the measuring light beam).

Next, heater tube 26 is removed so that the beam from lens 24 is emitted through slot 32. There being no illumination within sphere 31, the output of photocell 33 is zero. The output of photocell 19, of course, remains at its previous setting, and the output of differential amplifier 47 is at a maximum. Gain control 50 is now adjusted so that the meter 53 reads 100 (representing the condition corresponding to total absorption of the measuring light beam).

The previously selected clean spot on heater tube 26 is returned to point 25 and the meter 53 checked to see that it returns to zero. Other points on the meter now can be calibrated by inserting a series of standard absorption slides 29 into the light path and recording the meter reading for the particular slide. This need only be done once, or at infrequent intervals. In some embodiments, the total calibration of the meter will be performed at the factory and a provision such as slot 27 for receiving a calibrating slide will not be incorporated.

Having calibrated the meter reading to zero and 100 for a particular heater tube, an area of that tube having an apparently heavy deposit thereon is positioned at point 25. This deposit will absorb some of the light from the measuring light beam being impinged thereon. The light beam being impinged thereon (within the range of operation of interest) passes through the deposit to the aluminum surface, is reflected by the aluminum surface and returns out through the deposit to be integrated within sphere 31. Absorption occurs both as the light beam proceeds from the outside down to the aluminum surface and also as the light beam returns from the aluminum surface back out to the exterior of the deposit. Within the range of interest in the testing of fuels, there will be a substantially direct correlation between the thickness of the deposit and the amount of light that is absorbed. Thus, the amount of illumination within the integrating sphere 31 will be correspondingly reduced as compared to the amount of illumination when the light beam was impinged on the bare surface of the tube. The magnitude of the electrical pulses produced by photocell 33 will be correspondingly reduced, while the magnitude of the electrical pulses from photocell 19 will remain the same. The difference in magnitude of the two sets of pulses will

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appear as an output signal from differential amplifier 47 and will be read on meter 53 in terms of amount of absorption that occurred. Heater tube 26 is moved back and forth and around to make sure that a reading is taken at an area of the tube that produces the greatest amount of light absorption. If a strip chart were employed as the output indicator there would be a series of indications thereon with one or more of the indications being greater in magnitude (representing more absorption) than the others.

The temperature along a T.O.T. heater tube is not uniform, but it is possible to ascertain specific locations on the tube that will have predetermined temperatures. By selecting a series of locations that will have a range of temperatures, the thermal breakdown characteristics of the fluid hydrocarbon can be further ascertained.

After the calibration of the instrument to the tube (as previously discussed), readings are taken at the pre-selected locations of known temperatures. Thus, one will obtain a series of deposit-thickness readings for a graduated series of temperatures. This is done in only a single test (in the sense of one heating of the tube and developing a deposit thereon) as compared to the prior art practice of carrying out a number of tests to obtain comparable type information albeit less accurate.

In an actual embodiment the integrating sphere 31 was approximately 5 inches in internal diameter. Its interior surface would be of a relatively non-light absorbing character. The tube 26 is received within the sphere 31 by about half of the tube's diameter and the size of the light spot 25 on the tube surface is approximately 1 x 2 millimeters. The light projection system is positioned so that the axis of the light beam lies in a plane containing the axis of the tube 26 and is inclined about 80° from the tube axis so that specular reflection does not re-enter the lens 24. The photocell 33 is placed approximately 90° from the axis of the incident light beam.

Using a scale on the meter, the meter deflection is proportional to the percent absorption, and by suitable scale markings which can be correlated with the standard filters, a nonlinear scale can be inscribed on the meter face whose indications are in optical diffuse density where, as stated earlier, the optical diffuse density is equal to the logarithm of 1/(1-percent absorption) so that an absorption of 90% corresponds to a density of 1.0 and an absorption of 50% corresponds to 0.3. The range of interest in studying jet fuel deposit problems is about zero to 1.0 on the density scale. Using as a basis the standard optical density filters as previously discussed, the optical densities ranged from about 0.2 for a perceptible deposit to about 0.6 or 0.7 for a deposit rating over 4 on the prior art chip test presently in use.

I claim:

1. The method of using a light source and measuring the degree of deposit on a first portion of a thermal oxidation test heater tube which also has a second portion without a deposit thereon, said method comprising the steps of:

- (a) creating a first electrical signal indicative of the strength of light emanating from said source;
- (b) shining a beam from said source onto said second portion of said tube to be reflected therefrom;
- (c) integrating the light reflected from said second portion;
- (d) creating a second electrical signal indicative of the strength of the integrated light;
- (e) equating said electrical signals to represent the condition of complete reflectivity of said beam;
- (f) shining said beam from said source onto the first portion of the tube;
- (g) integrating the light reflected from said first portion;
- (h) creating a third electrical signal indicative of the strength of the integrated light reflected from said first portion; and

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- (i) comparing the third signal with said adjusted first signal to determine the extent to which the third signal is less than said equated first signal.
2. The method as set forth in claim 1, including the steps of:
- (j) after step (e) of claim 1, measuring the zero output that is obtained when the second electrical signal is subtracted from the first electrical signal to establish a complete reflectivity output measurement;
- (k) measuring said equated first electrical signal alone to establish a complete absorption output measurement; and
- (l) in step (i) of claim 1 measuring the third signal and determining where said third signal falls within the range between the complete absorption and the complete reflectivity measurements.
3. The method as set forth in claim 2, wherein said first portion of the tube is selected as being the one apparently having the heaviest deposit thereon.
4. The method as set forth in claim 3, wherein other portions apparently having deposits thereon are selected and steps (f), (g), (h), (i) and (l) are carried out with respect to each of said other portions.
5. The method as set forth in claim 4, wherein at least some of said other portions are selected by:
- ascertaining locations on said tube having various temperatures within the temperature range of interest when said tube is heated to the temperature employed when developing said deposit on said tube; and using said locations as said other portions.
6. The method as set forth in claim 1, including the steps of:
- ascertaining locations on said tube having various temperatures within the temperature range of interest when said tube is heated to the temperature employed when developing said deposit on said tube; carrying out steps (f), (g), (h) and (i) of claim 1 with the beam shining on each of said locations respectively.
7. The method of obtaining information as to the thermal oxidation characteristics of a fluid hydrocarbon by measuring the extent of deposit on a thermal oxidation test heater tube using an apparatus comprising first means for impinging a measuring beam of chopped light on a portion of said tube to be reflected therefrom so that the light reflected from said portion will depend in part on the deposit on said portion of the tube and for producing a reference beam of an intensity that is a function of the strength of the measuring beam, second means for receiving and integrating said reflected light both specular and diffuse, a first photoelectric cell positioned to receive said reference beam and produce a first pulsed electrical signal of a magnitude that is a function of the strength of the reference beam, a second photoelectric cell positioned to see the amount of the integrated light and to produce a second pulsed electrical signal of a magnitude that is a function of the amount of the integrated light, and a device connected to said cells for producing an output indication of the difference in magnitude of said signals, said method comprising the steps of:
- (a) ascertaining locations on said tube having various temperatures within the temperature range of interest when said tube is heated to a predetermined extent;
- (b) developing a carbonaceous deposit on said tube by contacting the tube heated to said extent with said hydrocarbon for a given period of time;
- (c) positioning one of said locations at the point of impingement and noting the output indication; and
- (d) repeating step (c) for said other locations.

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8. The method as set forth in claim 7, wherein prior to step (c) the following method for calibration is performed:
- positioning a part of the tube having no apparent deposit thereon at the point of impingement;
- adjusting the strength of the two electric signals to be equal to each other to obtain a zero output indication;
- removing the tube from the point of impingement so that there is no reflected light and adjusting the output to maximum indication.
9. The method as set forth in claim 8, wherein the following additional steps are carried out:
- (e) positioning a second part of the tube having an apparently heavy deposit thereon at the point of impingement and noting the output indication; and
- (f) repeating step (e) with other parts of the tube having a heavy deposit thereon.
10. The method of using a thermal oxidation test heater tube having a deposit on a portion thereof and an apparatus for measuring said deposit to obtain information as to the thermal oxidation characteristics of a fluid hydrocarbon, which apparatus comprises first means for forming a measuring beam of light, said first means directing said measuring beam onto a part of the tube so that at least part of said measuring beam of light is reflected therefrom, and a second means for integrating the specular and diffuse reflected light to produce an integral of the reflected light and indicating the relative amount of the integral reflected light when said part of the tube has a deposit thereon as compared to when said part of the tube has no deposit thereon, said method comprising the steps of:
- (a) ascertaining locations on said tube having various temperatures within the temperature range of interest when said tube is heated to a predetermined extent;
- (b) developing a carbonaceous deposit on said tube by contacting the tube heated to said extent with said hydrocarbon for a given period of time;
- (c) positioning one of said locations at the point of impingement and noting the output indication; and
- (d) repeating step (c) for said other locations.
11. The combination of a thermal oxidation test heater tube having a deposit on a portion thereof and an apparatus for measuring said deposit, said apparatus comprising first means for forming a measuring beam of light, said first means directing said measuring beam onto a part of the tube so that at least part of said measuring beam of light is reflected therefrom, and a second means for integrating the specular and diffuse reflected light to produce an integral of the reflected light and indicating the relative amount of the integral reflected light when said part of the tube has a deposit thereon as compared to when said part of the tube has no deposit thereon.

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MORRIS O. WOLK, Primary Examiner
R. E. SERWIN, Assistant Examiner

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