EFFECT OF FUEL MOLECULAR STRUCTURE ON SOOT FORMATION IN GAS TURBINE COMBUSTION*

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A number of studies have shown that for gas turbine combustors hydrogen content is a stronger correlating parameter for flame radiation than the more traditional properties of aromatic content or smoke point, especially when the fuels contain significant concentration of hydrocarbons other than paraffins and akyl-benzenes. The authors have shown that for light and middle distillate fuels viscosity and end point do not affect the correlation, leading to the conclusion that soot formation is primarily due to gas phase reactions rather than liquid phase pyrolysis. Some perturbations in the data suggest, however, that there are secondary effects due to hydrocarbon structure.

The purpose of this study is to indicate under what conditions and to what extent fuel variations at the same hydrogen content will affect soot formation in a gas turbine combustor. Six fuels were burned in a research combustor over a matrix of about 50 test conditions with test conditions ranging over 500-1800 kPa (5-18 atm) pressure and 500-1000 K burner inlet temperature; fuel-air ratios were varied from 0.008-0.024. Flame radiation measurements were made through a sapphire window toward the end of the primary zone. The hydrogen content of the six test fuels ranged from 12.80 to 12.88%. Five fuels emphasized different hydrocarbon types: aromatics (mono-, di-, and tri-cyclic), naphthenes (decalin) and partially hydrogenated aromatics (tetralin); the sixth fuel emphasized final boiling point.

Because of the large number of operating conditions, the data presentation has been simplified by first normalizing the flame radiation to that of a low aromatic Jet-A fuel at the same operating condition. This showed a consistent trend among the fuels that those with the unsaturated polycyclic ring compounds produced higher flame radiation. The results for each fuel were then averaged over all the operating conditions to produce a "radiation-index-R" for each fuel. Correlations were then made between this index and various fuel properties. The correlation with the smoke points of the fuels was surprisingly good, $r^2 = 0.94$; while aromatic content and total aromatic-ring carbon were poor correlating parameters, $r^2 = 0.49$ and 0.64 respectively; and obviously hydrogen content would not be good since all fuels had essentially the same hydrogen content.

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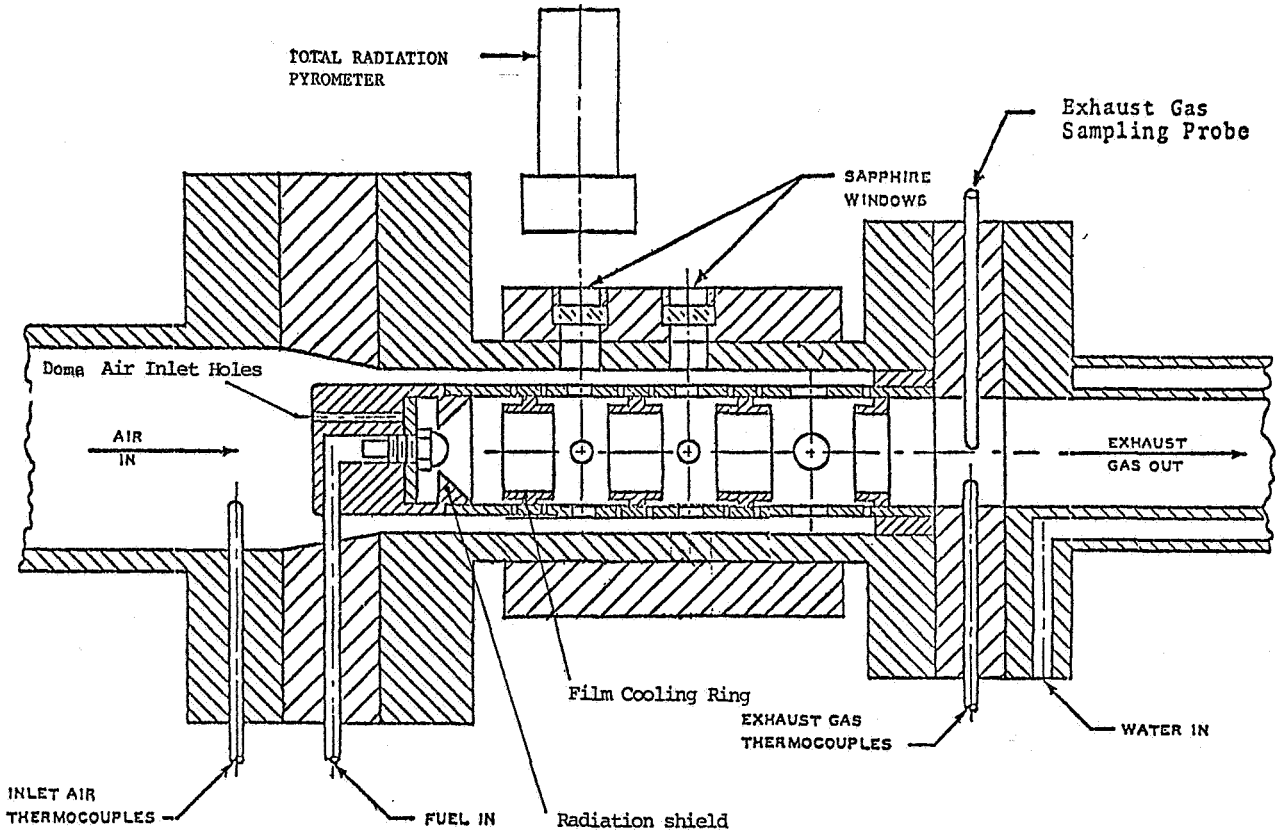
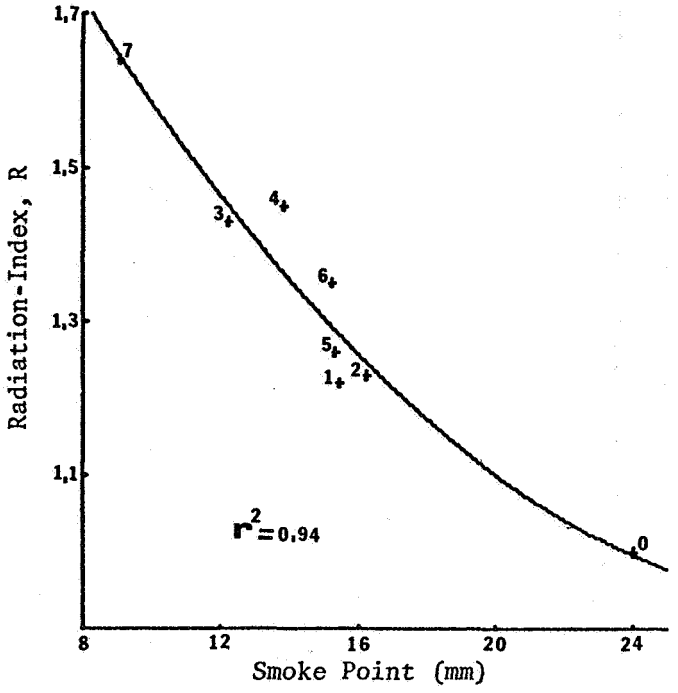
Fuels 1 and 2 with alkyl-benzenes and decalin had essentially the same flame radiation, confirming a hydrogen correlation in agreement with earlier work. The fuels with naphthalenes, tetralin, and anthracene produced higher radiation levels. For the fuels with naphthalenes and anthracene this increase in radiation above the hydrogen correlation, ΔR, correlated well with the percent of carbon that was tied up in the polycyclic aromatic rings. The fuel with tetralin produced radiation somewhere in between that of naphthalene and decalin, which is not surprising since its structure contains one saturated and one unsaturated ring.

The presence of about 20% polycyclic ring carbon is equivalent to a reduction in hydrogen content of a little over 1%. The sensitivity of flame radiation to the polycyclic aromatic contribution decreased as burner inlet pressure and as fuel/air ratio increased; inlet air temperature had no apparent effect.

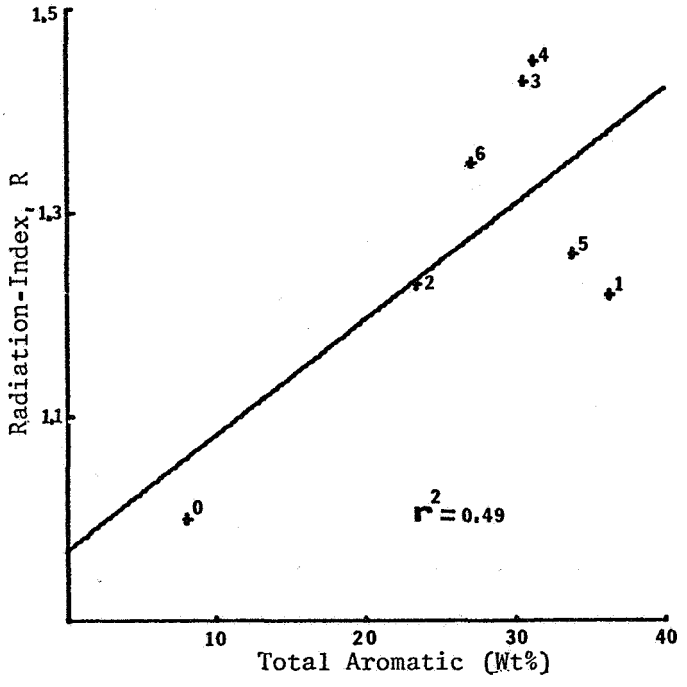


PHILLIPS 2-INCH COMBUSTOR

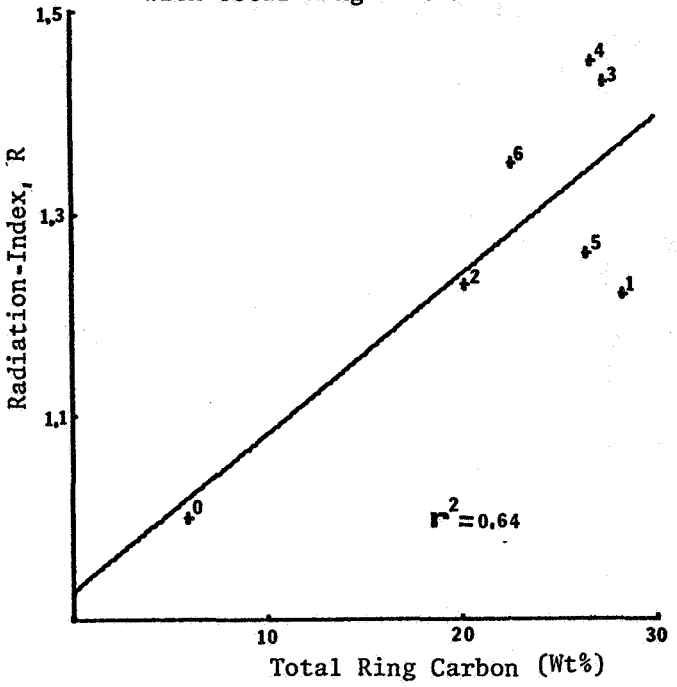
Correlation of Radiation Index with Smoke Point



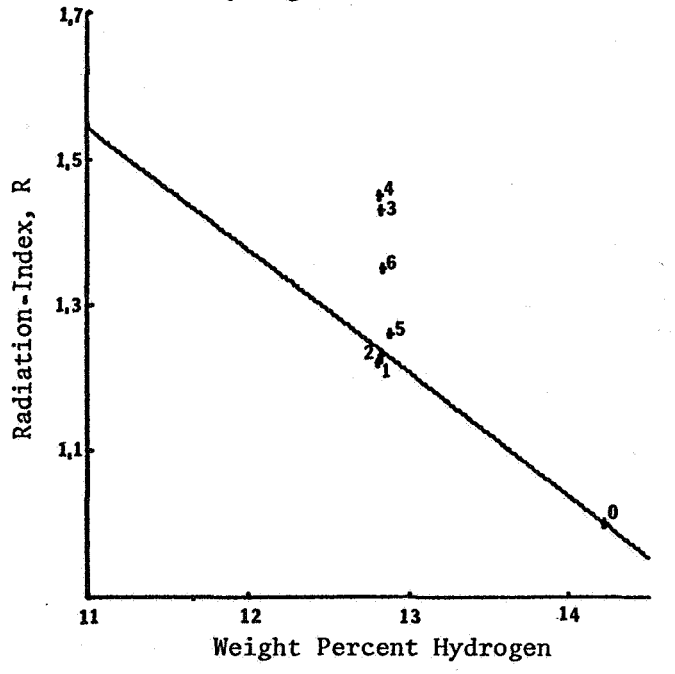
Correlation of Radiation-Index with Total Aromatics



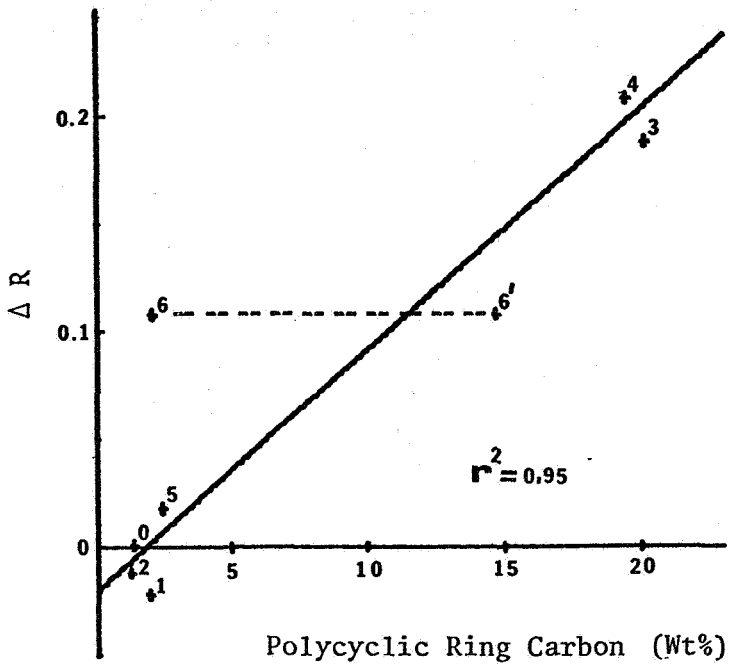
Correlation of Radiation-Index
with Total Ring Carbon

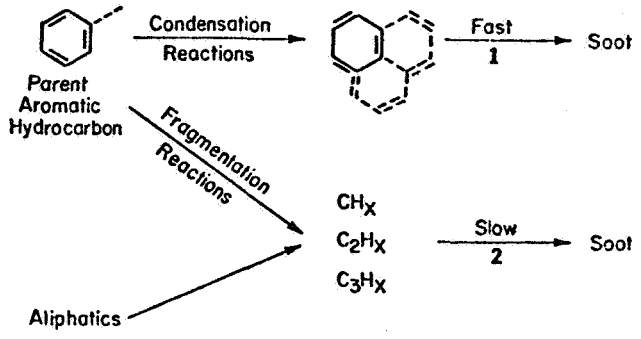


Correlation of Radiation-Index
With Hydrogen Content



Correlation of the Deviation (ΔR) in Radiation-Index From Hydrogen-Content-Correlation With Polycyclic Ring Carbon





- TYPICAL SYNCRUDE AROMATICS
  - alkyl-naphthalenes
  - tetralins
- TYPICAL PETROLEUM AROMATICS
  - alkyl-benzenes
- TYPICAL SYNCRUDE SATURATES
  - naphthenes
- TYPICAL PETROLEUM SATURATES
  - paraffins