15:18:38 OCA PAD INITIATION - PROJECT HEADER INFORMATION 09/14/95

Active

Project #: E-25-T80 Cost share #: Rev #: 0
Center # : 10/24-6-R8652-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: 811373-460 Mod #: Document : PO
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA:
Main project #: PE #:

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
BAIR S S III MECH ENGR (404)894-3273

Sponsor/division names: CUMMINS ENGINE CO /
Sponsor/division codes: 202 / 056

Award period: 950821 to 951027 (performance) 951027 (reports)

Sponsor amount	New this change	Total to date
Contract value	13,500.00	13,500.00
Funded	13,500.00	13,500.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: MEASUREMENT OF FUEL TRANSPORT PROPERTIES TO HIGH-PRESSURE

PROJECT ADMINISTRATION DATA

OCA contact: E. Faith Gleason 894-4820

Sponsor technical contact

FRED NERZ
(812)377-4608

CUMMINS ENGINE COMPANY, INC.
FUEL SYSTEM PLANT
1460 NATIONAL ROAD
P.O. BOX 3005
COLUMBUS, INDIANA 47202-3005

Sponsor issuing office

FRANCIS C. PROBST
(812)377-1191

CUMMINS ENGINE COMPANY, INC.
R&D TECH CENTER - MC50117
BOX 3005
COLUMBUS, IN 47201
FAX: (812) 377-6495

Security class (U,C,S,TS) : U
Defense priority rating :
Equipment title vests with: Sponsor GIT

ONR resident rep. is ACO (Y/N): N
supplemental sheet

Administrative comments -
INITIATION OF SPECIALIZED SERVICES AGREEMENT FOR "HIGH PRESSURE VISCOSITY MEASUREMENTS". REFERENCE P.O. # 811373-460 ON CORESPONDENCE AND INVOICES.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

PUBLICATION DELAYED UNTIL ~~up c/o~~

Closeout Notice Date 10/27/95 Due: 10/27/96

Project No. E-25-T80

Center No. 10/24-6-R8652-0A0

Project Director BAIR S S III

School/Lab MECH ENGR

Sponsor CUMMINS ENGINE CO/

Contract/Grant No. 811373-460

Contract Entity GTRC

Prime Contract No.

Title MEASUREMENT OF FUEL TRANSPORT PROPERTIES TO HIGH-PRESSURE

Effective Completion Date 951027 (Performance) 951027 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

E-25-T80 #1
(New)
(Final)

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

October 3, 1995

Fred Nerz
Cummins Engine Co., Inc.
Fuel System Plant
1460 National Road
P.O. Box 3005
Columbus, IN 47202-3005

Dear Fred:

Please find enclosed our final report detailing pressure-viscosity measurements performed on your fuel samples. As we discussed, a temperature-pressure-viscosity correlation is included as well as a method for estimating density (based on hexadecane) as a function of temperature and pressure.

Sincerely,

Scott Bair
Principal Research Engineer

enclosure

Administration Office 404-894-3200 • Finance Office 404-894-7400 • Graduate Program 404-894-3204 • Undergraduate Office 404-894-3203 • Fax 404-894-8336

HIGH-PRESSURE-VISCOSITY MEASUREMENTS

a final report to

Cummins Engine Co.
Fuel System Plant
1460 National Rd.
P.O. Box 3005
Columbus, IN 47202-3005

by

Scott Bair
Tribology and Rheology Laboratory
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

October, 1995

INTRODUCTION

The Georgia Tech Tribology and Rheology Lab has undertaken the measurement of viscosity of three diesel fuels to high pressure for various temperatures. Three test samples were provided by Cummins. A total of ten pressure-viscosity isotherms were obtained at temperatures of 0, 30 and 120°C for each oil and -40°C for one. This final report details the dynamic viscosity at various pressures from atmospheric pressure to 456 MPa or to the solidification of the sample as indicated by a viscosity increasing with time. The reciprocal asymptotic isoviscous pressure, α^*, is reported. In addition, parameters for a Free Volume Model have been calculated for the samples.

VISCOMETER

The pressure-viscosity results reported here were obtained with a falling body viscometer which applies a maximum shear stress of approximately 20 Pa. The reported viscosities may be assumed to be the limiting low shear viscosity owing to the very low shear stress. The viscosity measurement technique is discussed in Ref. [1].

RESULTS

The measured viscosities are listed in Table I. Each entry is the average of at least two falls - more at the lowest pressures. Measurements were routine. The pressure-viscosity coefficient which best represents the film forming capability in concentrated contact is α^*,

$$\alpha^* = \left[\int_o^\infty \frac{\mu(o)}{\mu(p)}\,dp\right]^{-1}$$

where p is pressure and μ is viscosity.

Sufficient data were obtained to regress the parameters for the Free Volume Model [2] shown below. These parameters are listed in Table II. The glass transition is regarded as an isoviscous process with viscosity, μ_g, at the glass transition temperature, T_g. Since the glass transitions of these samples were not measured, μ_g was arbitrarily taken to be 10^{10} Pa·s based on our experience with kerosene. Now, T_g represents a reference temperature rather than the true glass transition temperature. The relative free volume expansivity, F, can be empirically related to the liquid expansivity [2].

$$\mu = \mu_g \cdot \exp\left[\frac{-2.3\, C_1\, (T - T_g)\, F}{C_2 + (T - T_g)\, F}\right]$$

where

$$T_g = T_{go} + A_1 \ln(1 + A_2 p)$$

$$F = 1 - B_1 \ln(1 + B_2 p)$$

and A_1, A_2, B_1, B_2, C_1, and C_2 and T_{go} are parameters to be evaluated. The above relations may be used to find viscosity for conditions not measured for this report. The viscosity measured at the pressure immediately below the "solid" pressure was omitted from the regression.

DENSITY ESTIMATE

The relative density of n-Hexadecane as a function of temperature and pressure is assumed to approximate the density of a general diesel fuel. Using density measurements reported in ref [3], parameters for the Tait equation were regressed. The density, ρ, is obtained from

$$\frac{\rho(p,T)}{\rho(o,T)} = \left[1 - \frac{1}{K_o'}\,\ell n\left(1 + \frac{p}{K_o}\,(1 + K_o')\right)\right]^{-1}$$

where K_o is the bulk modulus at zero pressure and is a function of temperature given by

$$K_o = K_\infty + \dot{K}_o / T_K$$

where T_K is absolute temperature. The density at atmospheric pressure and temperature, T, is

$$\rho(o,T) = \rho(o,o)/(1 + aT_K)$$

Using published densities for temperatures from 20 to 99°C and pressures to 456 MPa we obtained:

K'_o	=	9.083
K_∞	=	0
$\dot{K}_o$	=	345 GPa·°K
$\rho(o,o)$	=	1.005 g/cm^3
a	=	1.028 X 10^{-3} °K^{-1}

An alternative form for K_o was found to more accurately reproduce K_o with some loss of accuracy for ρ.

$$K_o = K_\infty - \dot{K}_o T_K$$

for which

K'_o	=	9.11
K_∞	=	3.39 GPa
$\dot{K}_o$	=	0.00658 GPa/°K
$\rho(o,o)$	=	1.008 g/cm^3
a	=	1.033 X 10^{-3} °K^{-1}

REFERENCES

[1] Bair, S., "An Experimental Verification of the Significance of the Reciprocal Asymptotic Isoviscous Pressure," ASLE Tribology Trans., 36, 2 (1993).

[2] Yasutomi, S., Bair, S., and Winer, W., "An Application of a Free Volume Model to Lubricant Rheology," Trans. ASME Journal of Tribology, 106, 2 (1984).

[3] ASME Research Committee on Lubrication, Pressure Viscosity Report, ASME (1953).

TABLE I
Pressure-Viscosity Results (mPa·s)

	501			503			504			
P/MPa	0°C	30°C	120°C	0°C	30°C	120°C	-40°C	0°C	30°C	120°C
0.1	7.52	2.96	0.758	6.79	2.38	0.670	16.2	3.12	1.55	0.487
69	24.7	7.92	1.49	23.6	6.50	1.393	72.0	8.35	3.59	0.949
146	solid	18.72	2.69	113.8	16.15	2.44	solid	19.67	8.05	1.680
224		45.8	4.52	solid	36.8	4.34		49.1	16.44	2.62
301		110.4	7.29		88.3	6.60		119.5	34.1	4.16
378		solid	11.73		402	10.72		333	71.7	6.35
456			18.88		solid	16.85		solid	149.3	9.64
α^*/GPa^{-1}	---	13.0	8.06	18.7	13.4	8.32	---	13.1	11.1	8.17

TABLE II. FREE VOLUME PARAMETERS

SAMPLE	μ_gPa·s	T_{go}/°C	A_1/°C	A_2/GPa^{-1}	B_1	B_2/GPa^{-1}	C_1	C_2/°C
501	10^{10}	-104.0	19.02	6.464	0.3086	12.48	14.05	16.35
503	10^{10}	-106.2	19.02	6.463	0.3083	12.46	14.11	16.55
504	10^{10}	-127.9	17.22	6.146	0.3080	12.36	14.21	17.26

where

$$\mu = \mu_g \cdot \exp\left(\frac{-2.3C_1\,(T-T_g)\,F}{C_2 + (T-T_g)\,F}\right)$$

$$T_g = T_{go} + A_1 \ln(1 + A_2 p)$$
$$F = 1 - B_1 \ln(1 + B_2 p)$$