TECHNICAL SUPPORT DOCUMENT
FOR
PROPOSED ADOPTION OF REGULATIONS LIMITING THE SULFUR CONTENT AND THE AROMATIC HYDROCARBON CONTENT OF MOTOR VEHICLE DIESEL FUEL

APPENDICES

PA 1300

APPENDIX A

Consultation Meeting Notices

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 30, 1987

Dear Sir/Madam:

Consultation Meeting to Discuss
Inventories of Emissions From Diesel Motor Vehicles

The Air Resources Board (ARB) staff will hold a consultation meeting with interested parties to discuss draft inventories of emissions from diesel motor vehicles. The time and place of the meeting are shown below:

Date: December 15, 1987
Time: 10:00 a.m.
Place: Lincoln Plaza - Conference Room 1160
400 "P" Street
Sacramento, CA

I have enclosed the agenda for the meeting as well as the draft ARB inventories of emissions from diesel motor vehicles and related documentation. Interested persons are invited to present at the consultation meeting their views, comments, and other relevant information regarding the enclosed ARB inventory for diesel motor vehicle emissions.

The inventory of emissions from diesel motor vehicles is one component of the ARB program to investigate the feasibility of diesel fuel property modifications. The other two components of this ARB program are (a) the investigation of the relationships between diesel engine emissions and selected diesel fuel properties and (b) the investigation of the technical feasibility and the costs to California refinery operators of modifying diesel fuel properties. The relationships between diesel engine emissions and fuel properties are currently being investigated by the Coordinating Research Council (CRC). The feasibility and costs are being investigated by Arthur D. Little, Inc. in a study funded by the ARB.

If you have any questions regarding this meeting, please contact Bill Lovelace, Manager, Energy Section, at (916) 322-6019.

Sincerely,

Dean C. Simeroth, Chief
Criteria Pollutants Branch

Enclosures

Air Resources Board
Stationary Source Division

AGENDA

1. Status of the ARB Diesel Fuel Property Modification Program.

2. Inventory of Emissions from Diesel Motor Vehicles.

   a. Diesel Fuel Use and Projections

   b. Emissions Inventory

      . On-Road Motor Vehicles
      . Off-Road Motor Vehicles

3. Future Activities.

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, *Governor*

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

(916) 445-0650

6/3/88

Dear Sir/Madam:

Consultation Meeting to Discuss Modification of Motor Vehicle Diesel Fuel Properties

The Air Resources Board staff will hold a consultation meeting with interested parties to discuss possible changes to specifications for motor vehicle diesel fuel and the basis for those changes. Topics for discussion at the meeting include: (a) the results of the Arthur D. Little, Inc. (ADL) study on the costs of reducing aromatic hydrocarbon and sulfur levels in motor vehicle diesel fuels; (b) the effects of reducing aromatic hydrocarbon and sulfur content of diesel fuels on emissions from diesel-powered motor vehicles; (c) appropriate test methods for determining the aromatic hydrocarbon content and sulfur content of diesel fuels; and (d) regulatory options. The time and place of the meeting are shown below:

Date: June 27, 1988

Time: 9:30 a.m.

Place: McCandless Auditorium
South Coast Air Quality Management District
Headquarters
9150 Flair Drive
El Monte, CA

Attached is the agenda for the consultation meeting.

A second consultation meeting may be held to allow discussion of any unresolved issues. The time and place of the second meeting are shown below:

Date: July 7, 1988

Time: 9:30 a.m.

Place: Board Room
Department of Transportation
1120 "N" Street
Sacramento, CA

If the second consultation meeting is not needed, a cancellation notice will be sent to you.

The consultation meetings are part of the ARB program to prepare recommendations for the changes to the specifications for diesel fuel that we are preparing for presentation to the Air Resources Board next fall.

If you have any questions regarding the meetings, please contact Dean Simeroth, Chief of the Criteria Pollutants Branch, at (916) 322-6020.

Sincerely,

Donald A. Wiesen

for Peter D. Venturini, Chief
Stationary Source Division

Attachment

Consultation Meeting
June 27, 1988
Air Resources Board
Stationary Source Division

AGENDA

1. Status of the ARB Diesel Fuel Modification Program.

2. Results of the ADL Study.

3. Summary of Other Data on Costs for Aromatic Hydrocarbon and Sulfur Reduction.

4. Cost-Effectiveness Methods.

5. Methods of Estimating the Emissions Impact of Aromatic Hydrocarbon Reductions.

6. Methods of Estimating the Emissions Impact of Sulfur Content Reduction.

7. Test Methods for Aromatic Hydrocarbon Content and Sulfur Content of Diesel Fuels.

8. Regulatory Options.

9. Future Activities.

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, *Governor*

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

(916) 445-0650

July 22, 1988

Dear Sir or Madam:

Consultation Meeting to Discuss Modification of Motor Vehicle Diesel Fuel Properties

The Air Resources Board (ARB) staff will hold a consultation meeting with interested parties to discuss proposed regulations for motor vehicle diesel fuel composition, and the basis for such regulations. Topics for discussion at the meeting include: (a) the proposed regulations and limits for motor vehicle diesel fuel aromatic hydrocarbon and sulfur content; (b) the results of the ARB staff's analysis of the Coordinating Research Council (CRC) data and CRC's comments on the analysis; and (c) the results of the A.D. Little, Inc. study and the ARB staff's cost-effectiveness analyses. The time and place of the meeting are shown below:

Date: August 5, 1988

Time: 9:30 a.m.

Place: Department of Transportation
1120 "N" Street
Basement Board Room
Sacramento, CA

The consultation meeting will be an informal discussion of the topics described above. Those interested in these topics are urged to attend the meeting as they may miss valuable discussion of subjects that could be part of regulatory proposals or Air Resources Board action.

If you have any questions regarding this meeting, please contact Dean Simeroth, Chief of the Criteria Pollutants Branch, at (916) 322-6020.

Sincerely,

for Peter D. Venturini, Chief
Stationary Source Division

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812
(916) 445-0650

September 16, 1988

Dear Sir or Madam:

Consultation Meeting to Discuss Modification of Motor Vehicle Diesel Fuel Properties

The Air Resources Board (ARB) staff will hold its fifth consultation meeting with interested parties to discuss proposed regulations for motor vehicle diesel fuel composition, and the basis for such regulations. Topics for discussion at the meeting include: (a) the proposed regulations and limits for motor vehicle diesel fuel aromatic hydrocarbon and sulfur content; (b) the results of the ARB staff's analysis of emissions reductions from the proposed regulations; and (c) the results of the ARB staff's cost and cost-effectiveness analyses. I have enclosed a preliminary draft copy of our Technical Support Document for the proposed regulations for discussion at the meeting. The time and place of the meeting are shown below:

Date: September 27, 1988

Time: 10:00 a.m.

Place: San Francisco State Building
455 Golden Gate Avenue
Room 1158
San Francisco

The consultation meeting will be an informal discussion of the topics described above. Those interested in these topics are urged to attend the meeting as they may miss valuable discussion of subjects that could be part of regulatory proposals or Air Resources Board action. We plan on presenting regulatory proposals to the Board at the November 17-18, 1988 Board meeting.

It would be beneficial if you would come to the meeting prepared to discuss information on the topics listed below so that we may consider your input in preparing our proposal to the Air Resources Board:

- Emission reductions that would be achieved from reducing the sulfur and aromatic hydrocarbon content of motor vehicle diesel fuel.
- Feasibility of reducing diesel fuel aromatic hydrocarbon content.

- Capital and operating costs for reducing the sulfur and aromatic hydrocarbon content of diesel fuel.
- Cost of segregating motor vehicle diesel fuel from the rest of the No. 2 distillate pool.
- Lead time needed for implementing new motor vehicle diesel fuel specifications.
- Impacts on vehicle engines of reduced sulfur content and aromatic hydrocarbon content motor vehicle diesel fuel.
- Future availability of diesel fuel.

If you have any questions regarding this meeting or the requested information, please contact Dean Simeroth, Chief of the Criteria Pollutants Branch, at (916) 322-6020.

Sincerely,

Peter D. Venturini, Chief
Stationary Source Division

cc: Roberta Hughan, Board Member
Jack Lagarias, Board Member

Enclosure

APPENDIX B

Correspondence

CONCERNS

- NO_x "BENEFITS"
- ENGINE DURABILITY
- FUEL ENERGY CONTENT
- FUEL CLOUD POINT

NO_x "BENEFITS"

- NO_x RESPONSE TO FUEL PROPERTY CHANGES IS HIGHLY ENGINE SPECIFIC

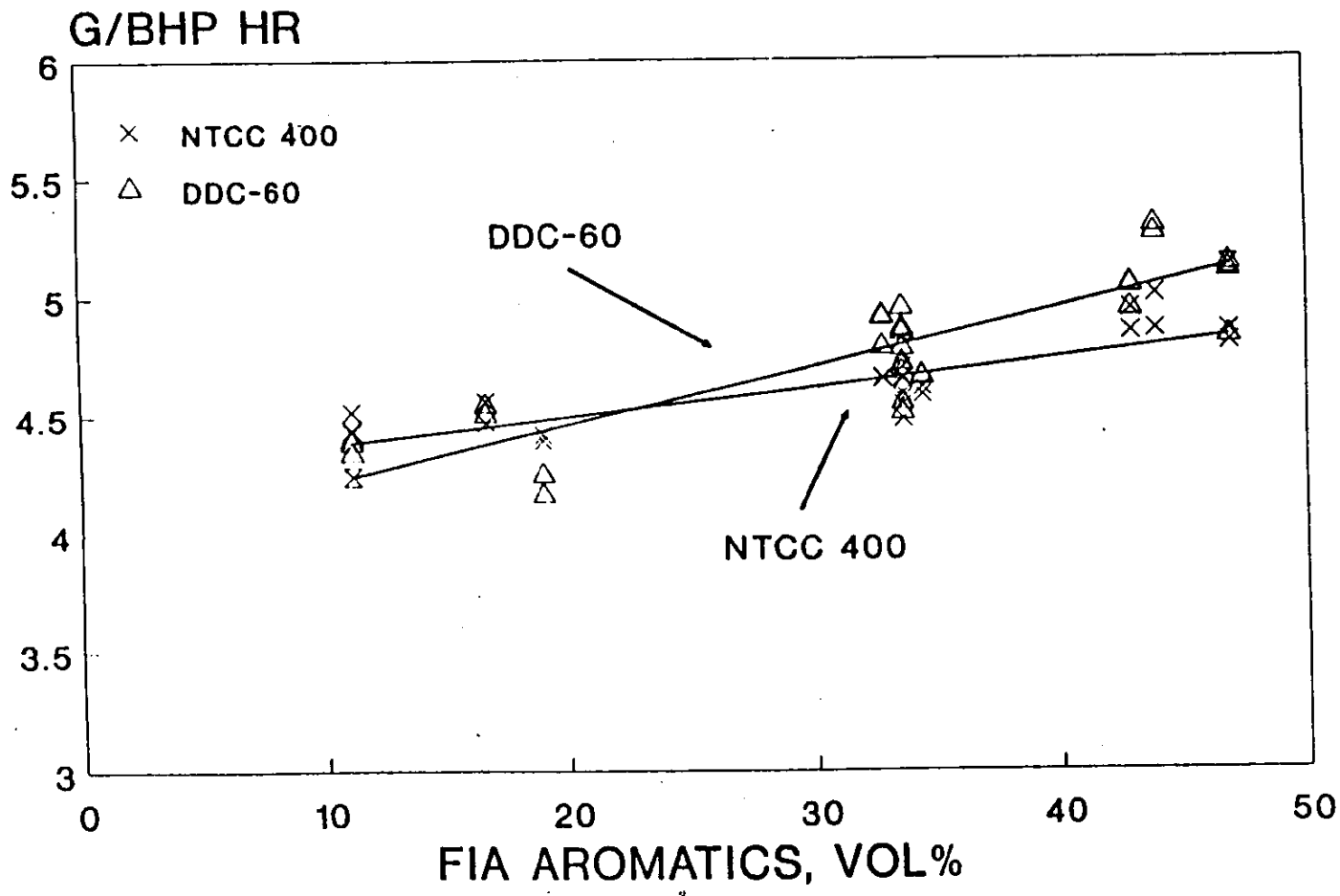
- NO_x IS NOT FUNDAMENTALLY RELATED TO FUEL AROMATICS

- NO_x IS MOST STRONGLY AFFECTED BY COMBUSTION TIMING

WEIGHTED NITROGEN OXIDES

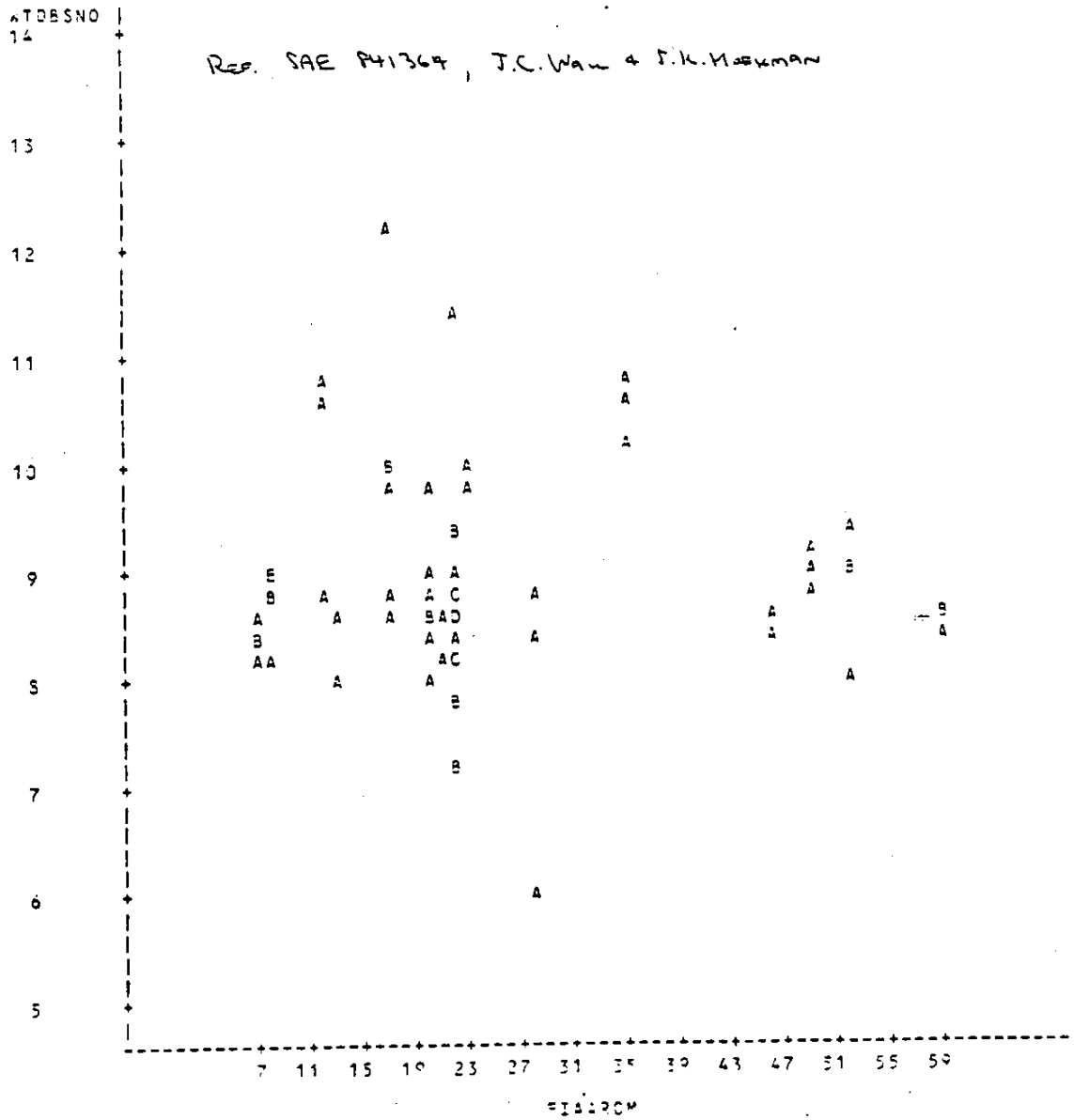
EPA TRANSIENT TEST

VE-1 DATA



CUMMINS NTC-290 NOX EMISSIONS VERSUS FIA AROMATICS CONTENT

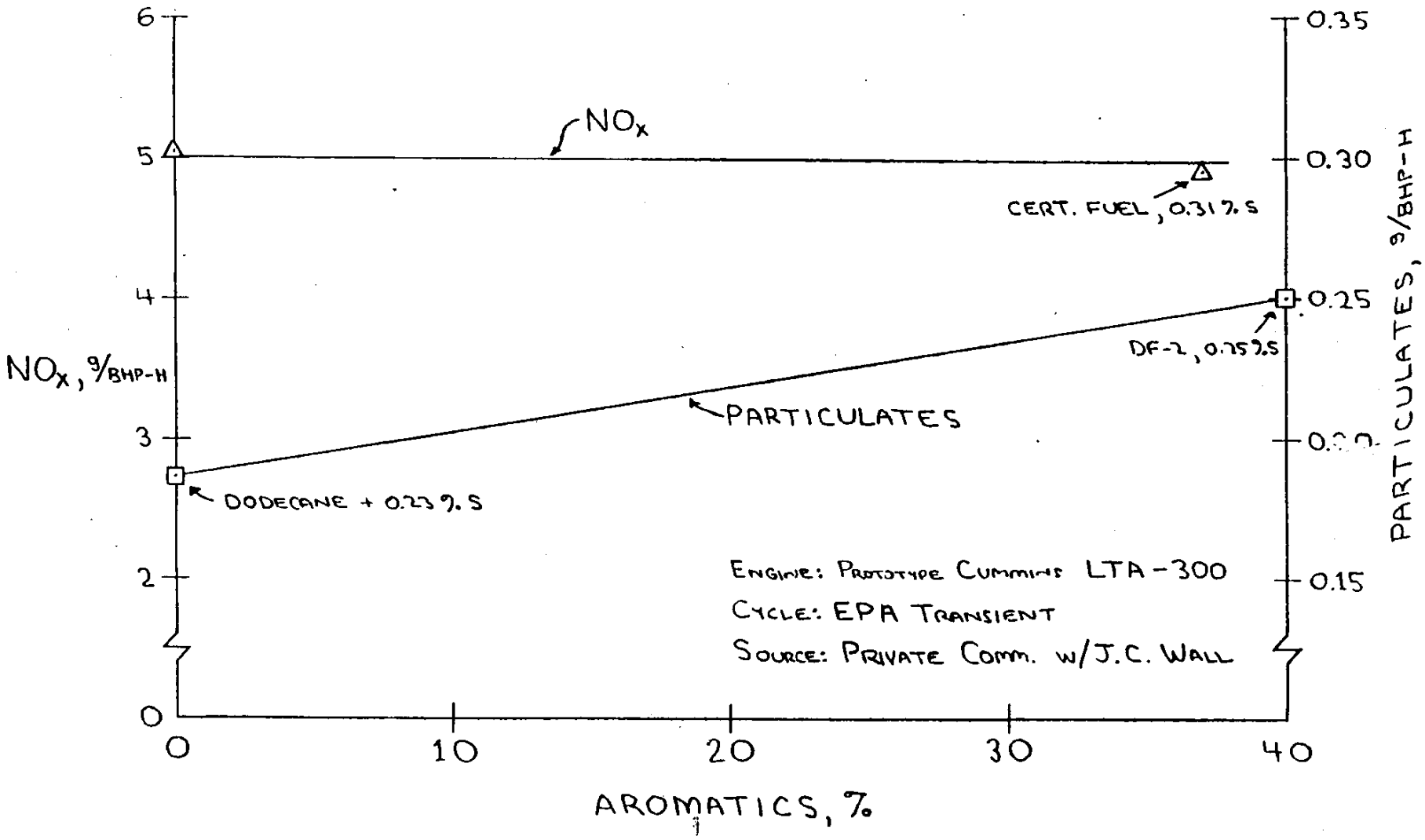
PLOT OF WTDBSNO*FIAAROM LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Ref. SAE 841364, J.C. Wall & T.K. Hoekman

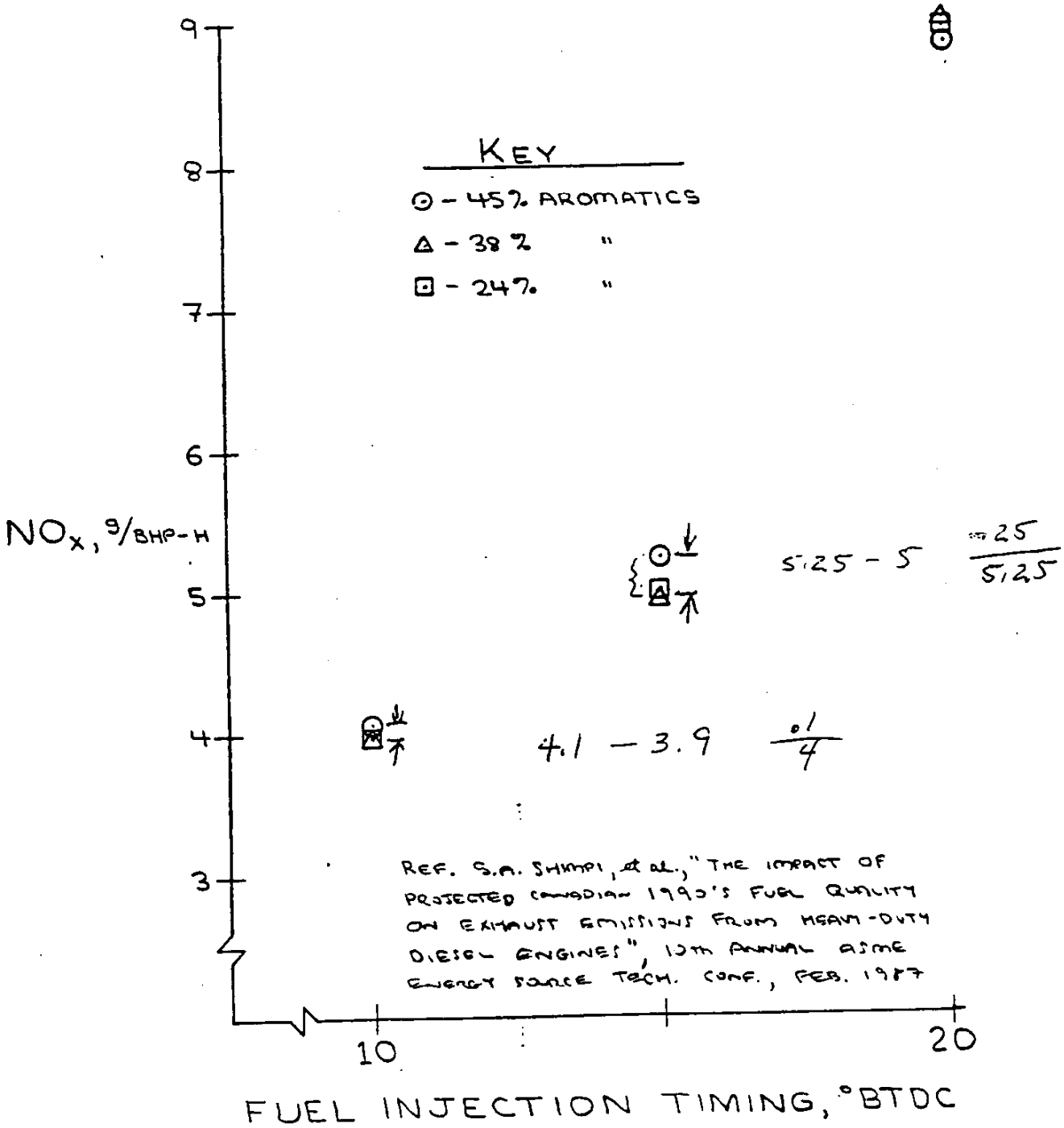
NOTE: 74 OBS HAD MISSING VALUES

EFFECT OF AROMATICS ON NO_x AND PARTICULATE EMISSIONS



MCI 9/12/88

EFFECT OF INJECTION TIMING ON NO_x
CUMMINS NTCC-400



REF. S.A. SHIMPI, et al., "THE IMPACT OF PROJECTED CANADIAN 1990'S FUEL QUALITY ON EXHAUST EMISSIONS FROM HEAVY-DUTY DIESEL ENGINES", 10th ANNUAL ASME ENERGY SOURCE TECH. CONF., FEB. 1987

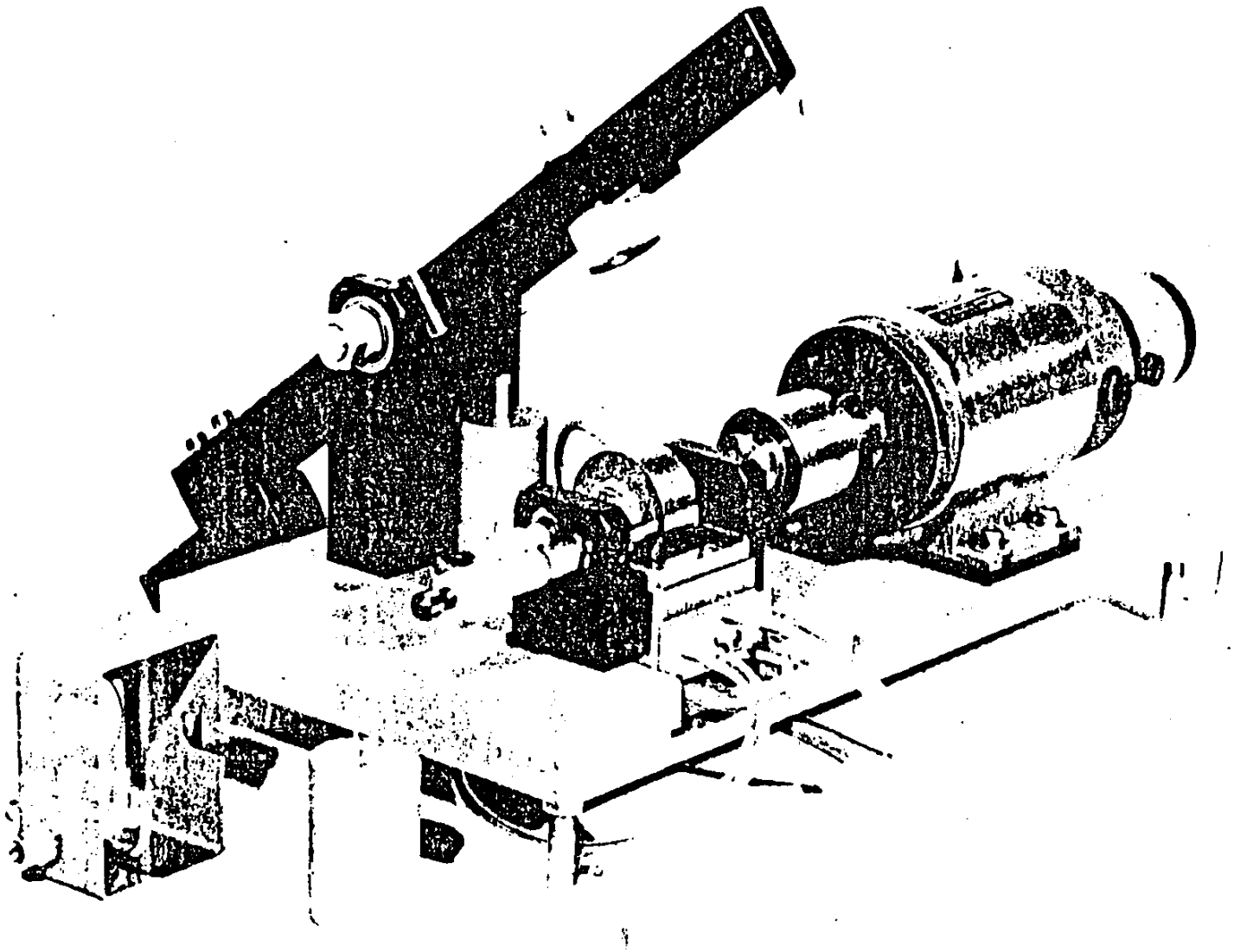
MCI 9/12/88

ENGINE DURABILITY

- SEVERE HYDROPROCESSING ADVERSELY AFFECTS FUEL LUBRICITY

- ASTM LUBRICITY TESTS OF VE-1 FUEL & SHOW 8-9 TIMES HIGHER WEAR RATE THAN CURRENT DIESEL FUELS

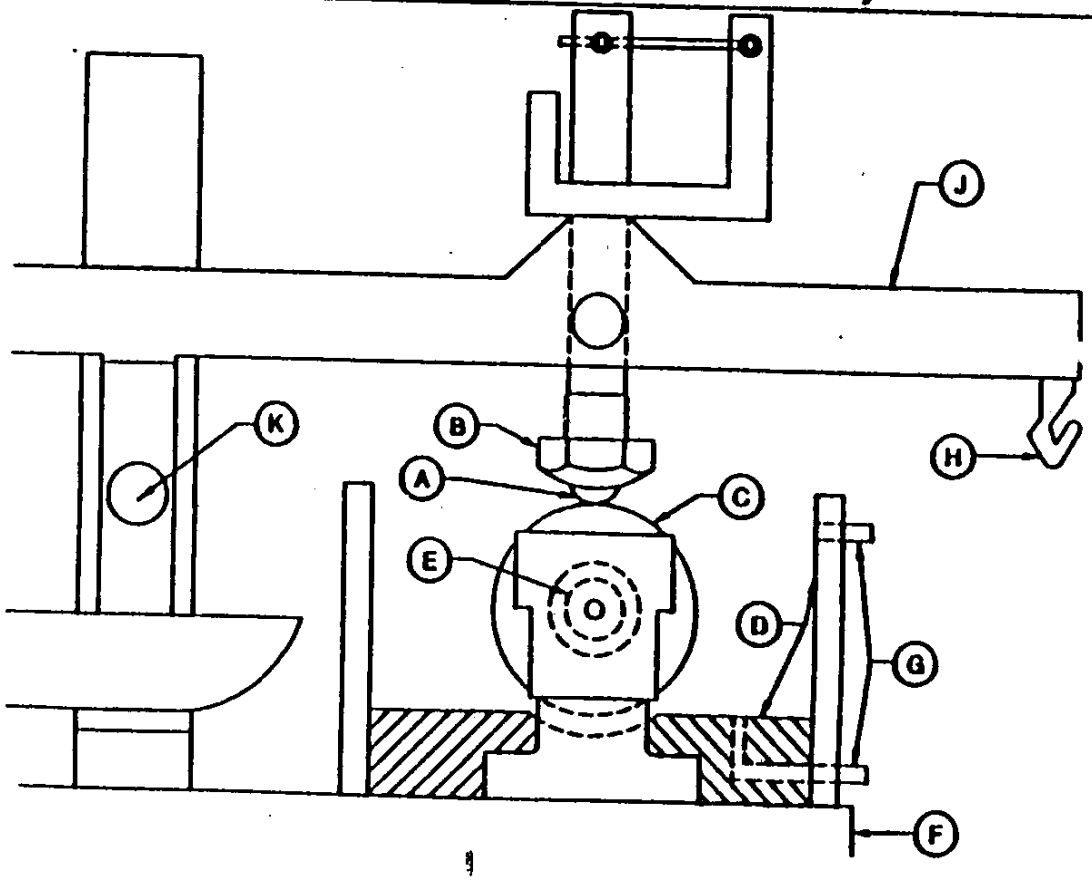
FIGURE Q-2



BALL-ON-CYLINDER LUBRICITY TESTER

FIGURE 5

SCHEMATIC OF BALL-ON-CYLINDER LUBRICITY EVALUATOR (BOCLE)



SEVERE HYDROPROCESSING ADVERSELY AFFECTS FUEL LUBRICITY

DIESEL FUEL NO. 2	BOCLE RELATIVE WEAR RATE	Aromatic
COMMERCIAL PRODUCTS		
CHEVRON RICHMOND	1.4	25
CHEVRON EL SEGUNDO ULSD	1.2	22
[redacted]		
VE-1 FUELS		
FUEL 8 BEFORE HYDROPROCESSING	1.0	34
FUEL 8 HYDROPROCESSED TO 10% AROM.	8.7	10

HYDROPROCESSING FOR AROMATICS REDUCTION INCREASED WEAR RATE 9-FOLD

FUEL ENERGY CONTENT

- SEVERE HYDROPROCESSING REDUCES VOLUMETRIC ENERGY CONTENT

- VE-1 FUEL 8 HAS ~2% LOWER ENERGY CONTENT THAN CURRENT CA DIESEL FUELS

American Independent Refiners Association

SMALL REFINERS' POSITION PAPER ON THE SULFUR AND AROMATIC CONTENT OF DIESEL FUEL

August 29, 1988

In connection with the regulations planned by the California Air Resources Board ("ARB") to reduce the sulfur and aromatics content of diesel fuel, the small refiners in the State of California have adopted this position paper. As defined by ARB in its proposed Section 2256(c)(12) and used here, small refiners are those with a refining capacity of not more than 50,000 barrels per stream day in California. Small refiners represent approximately 13 percent of the total diesel fuel production of about 153,000 barrels per day. Additionally, small refiners supply a substantial amount of the gasoline sold in California, 18 percent of the military jet fuel sold in California, all of the asphalt sold in Southern California and 50 percent of the asphalt sold in Northern California.

Although each small refiner individually represents a small share of the market, their cumulative influence is substantial and decidedly pro-competitive. The Federal Trade Commission, the Attorney General of California, and other state and federal regulatory agencies have acknowledged the important influence of small refiners in mitigating the anti-competitive effects of concentrating the supply of petroleum products in the hands of a few companies. With respect to diesel fuel specifications, the small refiners seek a way to achieve the maximum amount of air quality improvement without eliminating the competitive viability of many small refiners, whose continued existence is already threatened by poor refining margins, the high cost of compliance with environmental requirements and uncertain access to supplies of crude oil.

West Coast Office
649 South Olive Street, Suite 500 • Los Angeles, California 90014 • (213) 488-1748

Washington D.C. Office
50 F Street, N.W., Suite 1040 • Washington, D.C. 20001 • (202) 783-0643

For purposes of this position paper, the small refiners have utilized the costs set forth in the draft document prepared by ARB staff entitled "Comparisons In Cents Per Gallon of Diesel Fuel Produced by Using Different Data Sources" ("Cost Summary Document") attached hereto. The Cost Summary Document shows a dramatically higher cost for small refiners than for large refiners in each regulatory scenario. The small refiners seek a scenario in which the small refiners would not be forced to spend substantially mroe than large refiners on a cents per gallon basis. This paper now turns to a discussion of the small refiners' proposals for reducing the sulfur content of diesel fuel and the aromatic content of diesel fuel.

I. Sulfur Content of Diesel Fuel

We first propose that ARB grant small refiners one additional year beyond the currently proposed October, 1993 deadline to meet the reduction in diesel fuel sulfur content to the level of 500 parts per million by weight. The additional year would allow existing small refiners time to pursue financing of hydrodesulfurization projects either individually or in cooperative joint ventures. During that additional year, small refiners would be allowed to sell motor vehicle diesel fuel outside of the South Coast Air Basin and Ventura County containing not more than 5,000 parts per million by weight, the currently authorized sulfur content. Sales in the South Coast Air Basin and Ventura County would not be effected but rather would remain subject to Section 2252.

Since small refiners produce only about 13 percent of the diesel fuel sold in the State of California, at least 87 percent of the air quality benefit sought by the ARB would be obtained during the brief extended deadline. After the one year period, all of the air quality improvements sought would be obtained. Accordingly, nearly all the air quality benefits sought could be obtained without implementing measures that would eliminate many small refiners from the motor vehicle diesel fuel market in 1993.

II. The Aromatics Content of Diesel Fuel

The California statewide average for aromatic levels of motor vehicle diesel fuel is estimated by ARB staff to be about 35 percent. Many of the large refiners have taken the position that reducing the aromatic content of diesel fuel is not cost effective. This argument has even greater merit as applied to small refiners, whose costs per gallon to reduce aromatics, according to the Arthur D. Little data as adjusted by the ARB staff, are two to four times as high as the costs to the large refiners. In the event that ARB decides to require aromatics reduction of diesel fuel produced by small refiners despite the high cost and minimal air quality benefit, the small refiners propose that ARB limit aromatics content of diesel fuel sold by small refiners to a range between 30 and 40 percent effective October, 1993.

The actual level specified should be one that can be met without construction of units other than those necessary to reduce the sulfur content of diesel fuel. The proposed regulation requires that ASTM Test Method D 1319 84 or other method determined to give equivalent results be used to determine aromatics content. Some of the small refiners are concerned that this test method results in inaccurately high levels of aromatics, especially on napthenic feedstocks such as those from the Central Valley of California. Some of the small refiners are concerned because they have not tested the aromatics content of their diesel fuel by the proposed method. Accordingly, until an acceptable alternative test can be designated or until the results under the proposed method can be determined by all refiners, we are unable to specify a particular level for aromatics content.

The level chosen would ensure that after the October, 1993 deadline set forth in the proposed regulation, the motor vehicle diesel fuel manufactured and sold by each refiner would contain a lower aromatic content than the average aromatic content of motor vehicle diesel fuel sold under current regulations. Moreover, since small refiners represent approximately 13 percent of the market, the vast majority of motor vehicle diesel fuel sold in California would be the ultra-low aromatics diesel fuel mandated by the proposed regulation.

III. Permitting of Units Necessary to Meet Requirements of Proposed Regulations

Small refiners are concerned about the ability and willingness of the South Coast Air Quality Management District ("South Coast District") and other local air pollution controls districts to issue permits timely to construct units needed to comply with the various fuels specification regulations proposed by the ARB. The small refiners propose that language be included in the proposed regulations requiring the local air pollution control district to expedite review of permit applications. If permits to construct cannot be timely issued despite due diligence by the companies seeking permits, the applicable deadlines should be extended until units can be built.

Additionally, permit applicants for construction of units needed to comply with new regulations on fuels specifications should not have to provide offsets in the same manner as companies just beginning to do business in the particular air basin. For example, the South Coast District proposes to eliminate the use of shutdown credits as offsets and to limit offsets from technological changes to those from "innovative" technology. Other offsets will be distributed by the South Coast District pursuant to a set of criteria which may not ever make offsets available to anyone and, at the present, does not value changes to a facility required to comply with environmental regulations any differently from changes to expand production. If ARB regulations require the construction of additional units, a business should have some comfort that it will be allowed to construct such units.

IV. Conclusions

On a cents per gallon basis, this regulatory scenario would still result in small refiners spending more than large refiners. It is assumed here that small refiners would be able to achieve the aromatics level by blending, thus avoiding the tremendous capital outlays that otherwise would be required to reduce the aromatics content of diesel fuel. Instead, units only will have to be constructed to desulfurize diesel fuel. Although these units still would cost small refiners more than it would cost large refiners to desulfurize and dearomatize, small refiners could avoid the devastating effect of the additional amounts of capital required for a small refiner to reduce aromatics content to 20 percent. Unlike major oil companies, small refiners do not have access to substantial capital. Available credit of a small refinery is almost always fully utilized just to purchase crude oil and keep up with day-to-day requirements. Accordingly, even if small refiners would like to construct

the units necessary to produce ultra-low aromatics diesel fuel, they would be unable to obtain the financing necessary to undertake such changes. To meet the sulfur content requirements, small refiners need more time than large refiners to develop capital, engineering and land. Small refiners require more time to locate available land since most are constrained in size and sufficient land is not immediately available within the existing refinery. Small refiners do not have sufficient engineering staff to develop these projects and must contract with engineering firms to provide the needed expertise. Finally, small refiners cannot meet the capital requirements to achieve the proposed 20 percent aromatics level.

Small refiners believe that the foregoing proposals achieve nearly all the air quality improvements sought by the regulations currently proposed by ARB staff without implementing policies that would ensure the demise of small refineries in California. Although still painful to small refiners, the proposals provide a more level playing field than other alternatives which would cost small refiners substantially more than large refiners.

DRAFT

Comparisons in Cents per Gallon of Diesel Fuel Produced by Using Different Data Sources

Regulatory Scenario	Costs (cents per gallon)				
	1984 Survey a/	NPRA Survey	ADL Study	ARB's Adjustment to ADL Study	Adding H_2 Plant Capacity and Doubling the Capital Costs
0.05% S					
small refiners	7.3	17.8	13.6	13.6	17.3
large refiners	2.0	2.5	1.2	1.2	2.6
0.05% S and 20% Aromatics					
small refiners	-	70.0	19.5	19.0	26.4
large refiners	-	8.1	4.8	4.8	9.0
0.05% S and 15% Aromatics					
small refiners	-	-	17.6	16.8	27.6
large refiners	-	-	10.1	7.0	13.1
0.05% S and 10% Aromatics					
small refiners	11.2	-	138.0	27.0	42.5
large refiners	15.2	-	12.7	6.7	12.5
0.05% S and 10% Aromatics with Purchased Feedstocks					
small refiners	-	-	37.5	42.8	57.2
large refiners	-	-	11.4	16.3	22.3

a/ 1983 dollars

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

(916) 445-4383

August 19, 1988

Mr. Douglas Henderson
Executive Director
Western Oil and Gas Association
505 North Brand Blvd., Suite 1400
Glendale, CA 91203

Dear Mr. Henderson:

Draft Regulations for the Sulfur and Aromatic Hydrocarbon Content of Diesel Fuel

This is in response to your August 3, 1988, letter to me regarding the development of regulations to control the sulfur content and aromatic hydrocarbon content of diesel fuel. In your letter you presented a number of technical concerns related to the measurement, cost, and administration of diesel fuel composition requirements. You stated, regarding these issues, that oil industry representatives have not had sufficient time to review information presented at workshops. You also requested that any action we might take be deferred pending further discussion of the technical issues.

By way of background, we have held four workshops on the subjects of diesel fuel emissions, emission reductions that could be achieved from diesel fuel composition requirements, cost for different composition requirements, and regulatory formats. At the last workshop on August 5, 1988, the staff presented our analysis of costs of diesel fuel modifications, emission reductions and cost-effectiveness. We also distributed draft copies of proposed regulations to control the sulfur content and the aromatic hydrocarbon content of diesel fuel. The information presented at the August 5 workshop included refined versions of information discussed at earlier workshops, and responded to comments that we received at those earlier workshops.

At our workshops, we received a number of comments on technical issues and other issues that you mentioned in your August 3 letter, including test methods for diesel fuel aromatic hydrocarbon content. Regarding your concerns on the latter issue, this has been a topic at workshops and my staff met with WOGA representatives at your headquarters to discuss test methods on June 6, 1988. I want to assure you that we are very aware of your concerns on this and other technical issues and they will be addressed in any proposal that we make.

We consider the matter of diesel fuel regulations to be one of the important steps that we can take in improving air quality in California. For this reason, we consider your industry's input very important in our process, and feel that your concerns need full consideration. As you may be aware, I have rescheduled this item for presentation to the Board from the October to the November 1988 Board meeting. I urge you and your member companies to expedite the availability of any information related to this topic so that we may be able to incorporate such additional information into our proposal to the Air Resources Board. Specifically, we would appreciate receiving information on:

- Emission reductions that would be achieved from reducing the sulfur and aromatic hydrocarbon content of motor vehicle diesel fuel.
- Feasibility of reducing diesel fuel aromatic hydrocarbon content.
- Capital and operating costs for reducing the sulfur and aromatic hydrocarbon content of diesel fuel.
- Cost of segregating motor vehicle diesel fuel from the rest of the No. 2 distillate pool.
- Lead time needed for implementing new motor vehicle diesel fuel specifications.
- Impacts on vehicle engines of reduced sulfur content and aromatic hydrocarbon content motor vehicle diesel fuel.
- Future availability of diesel fuel.

To make sure that we consider all comments and concerns in our proposal to the Board, I have directed my staff to hold a fifth workshop on this topic. The workshop will be held during the week of September 19, 1988. A formal notice will be issued in the near future. I hope that we can receive the information that I have requested before the workshop.

Thank you for your cooperation in this matter. If you have any questions or further comments, please contact me.

Sincerely,

William W Sylte

for James D. Boyd
Executive Officer

bcc: Ms. Jananne Sharpless, ARB Board Member
Mr. George Bally, ARB Board Member
Dr. Eugene Boston, ARB Board Member
Mrs. Roberta Hughan, ARB Board Member
Mrs. Betty Ichikawa, ARB Board Member
Mr. John Cefala, ARB Board Member
Mr. John LaGarias, ARB Board Member
Mrs. Harriet Wieder, ARB Board Member
Dr. Andrew Wortman, ARB Board Member

To: California Air Resources Board
Stationary Source Division

From: Chevron Research Company

Subject: ARB Diesel Fuel Regulatory Proposals

Submitted: August 5, 1988 - Consultation Meeting to Discuss Modifications of Motor Vehicle Diesel Fuel Properties

As the Stationary Source Division staff are aware, Chevron Research has conducted extensive research into the effects of diesel fuel composition on the exhaust emissions from heavy-duty diesel engines. At the July 7, 1988 workshop on this same topic, we made the point that further analysis of our data indicates that carbonaceous particulate emissions are most strongly correlated with the multi-ring aromatics content of the fuel, as measured by mass spectrometry. You asked for documentation to support this contention.

The attached documentation consists of tabulations of fuel property data and particulate emissions regression results from our own test program, as well as from the Coordinating Research Council VE-1 study. Also attached are mass spectrometry hydrocarbon analyses of diesel fuel feed and product samples drawn the hydrodesulfurization units at our Richmond and El Segundo refineries.

Page 1 of the attachment presents inspection data for the fuels used in our in-house fuel effects studies. This is the same body of fuel data previously discussed by John Wall and Kent Hoekman in SAE Paper No. 841364. Reading from left to right, the data consist of fuel identification number (DNO), sulfur content (S), FIA aromatics content (FIAAROM), mass spec. total aromatics content (MSMAROM), mass spec. multi-ring aromatics content (MSMMULTI), mass spec. single-ring aromatics content (MSMMONO), distillation ninety percent boiling temperature in degrees C (D8690C), cetane number (CET) and calculated cetane index (CCI).

Pages 2 and 3 are SAS regression results for weighted particulate emissions from our in-house test program using a Cummins NTC 290 engine. You will recall that our tests were conducted at steady-state operating conditions, and that the emissions data were weighted in accordance with the EPA 13-mode test procedure. We have used the SAS procedure STEPWISE to perform these regressions, and we have chosen the MAXR option which selects independent variables in order of their decreasing contribution to the improvement of the degree of fit of the model. The independent variables we have specified for this regression are sulfur content, multi-ring aromatics content, single-ring aromatics content and ninety percent point.

Preliminary

Note that the first variable selected by STEPWISE is sulfur content, which provides an R-squared value of 0.75. The next variable chosen is multi-ring aromatics, which improves the R-squared to 0.92. Ninety percent point is brought in next, followed by mono-aromatics. Note that neither of these variables contributes much improvement to R-squared. Also note that while the coefficients for sulfur and multi-ring aromatics are statistically significant, the coefficients for ninety percent point and mono-aromatics are not. In particular note that the standard error associated with the coefficient for mono-aromatics is larger than the coefficient itself.

Page 4 is a tabulation of the fuel property data for the VE-1 program. We have added a variable for the multi-ring aromatics, which is simply the difference between the total aromatics content and the mono-aromatics content, as measured by mass spec.

Pages 5 and 6 are STEPWISE regression results for VE-1 weighted particulate emissions from the Detroit Diesel Series 60 engine. The data have been weighted in accordance with the EPA transient test procedure (one-seventh cold-start and six-sevenths hot-start). The same independent variables were specified for this regression as were used for our own data. Note that sulfur is again the first variable selected, indicating its importance in predicting total particulate emissions. Multi-ring aromatics are brought in next, improving R-squared from 0.65 to 0.83. Mono-aromatics come in next with a <u>negative</u>, but statistically insignificant, coefficient and no improvement in R-squared. Finally ninety percent point is added, again providing no improvement in R-squared.

Pages 7 and 8 present similar regression results for the S-2 steady-state particulate emissions data from the Series 60 engine. Again, the regression shows that sulfur and multi-ring aromatics are the only meaningful predictors for particulate emissions. Pages 9 and 10 present regression results for the S-2 steady-state data from the Cummins NTCC 400 engine in the VE-1 program. For these data, multi-ring aromatics is selected first, followed by ninety percent point and sulfur, all of which have statistically significant coefficients. Mono-aromatics are brought into the regression last, with little contribution to R-square.

Based on these data, it is our view that sulfur is the most important fuel parameter affecting heavy-duty diesel particulate emissions. To the extent that aromatics affect the carbonaceous fraction of the particulates, it is clear that multi-ring aromatics are the important parameter and that single-ring aromatics make no substantive contribution.

Preliminary

Pages 11 through 16 present mass spectrometry breakdowns of the hydrocarbons in samples of diesel fuel drawn from the feed and product streams of the hydrotreaters currently in use in our El Segundo and Richmond refineries. We would like to make two points with these data. First, there is a net reduction in total aromatics content which accompanies the desulfurization occurring in these process units. Second, there is a significant conversion of multi-ring aromatics to single-ring aromatics which also accompanies the desulfurization.

Extension of the current 500 ppm sulfur limit in the SCAB to the entire State of California, or more probably the entire nation, will require widespread utilization of hydrodesulfurization equipment. It is our contention that there will be an incremental bonus, in terms of particulate reduction, associated with the requirement for low sulfur fuel. This bonus is the result of the incremental reduction in total aromatics content and the conversion of multi-ring aromatics to single-ring aromatics which accompanies desulfurization. As a result, the cost-effectiveness of a sulfur content regulation becomes even more attractive.

Conversely, since the particulate emissions from advanced technology engines such as the Detroit Diesel Series 60 appear to be nearly insensitive to aromatics content, the cost effectiveness of a aromatics content regulation becomes prohibitive.

We believe that the only justifiable regulatory recommendation which the Stationary Source Division can make to the Air Resources Board in October is for a statewide 500 ppm sulfur maximum in on-highway diesel fuel.

Preliminary

FUEL PROPERTY DATA FOR CHEVRON FUEL EFFECTS STUDIES

REFERENCE: SAE PAPER NO. 841364

OBS	DNO	S	FIAAROM	MSMAROM	MSMMULTI	MSMMONO	D86900	CET	CCI
1	2646	0.12	24	22.4	10.1	12.3	262.778	43	44.4730
2	2647	0.45	26	23.2	9.8	13.4	321.667	38	39.6266
3	2845	0.05	13	13.0	6.9	6.1	316.667	64	63.8474
4	2857	0.10	52	51.4	28.4	23.0	292.222	28	32.5309
5	2858	0.15	46	42.9	18.6	24.3	305.000	31	35.0325
6	2860	0.18	21	21.6	6.5	15.1	310.000	43	42.9811
7	2861	0.03	7	10.3	3.9	6.4	305.000	56	58.2401
8	2862	0.11	28	20.8	5.0	15.8	247.222	42	39.8430
9	2876	0.45	22	26.6	11.2	15.4	327.778	45	45.0228
10	2891	0.02	37	29.0	7.1	21.9	311.667	36	42.5334
11	2892	0.57	.	58.0	48.1	9.9	371.667	32	45.3143
12	2893	0.10	20	15.6	9.2	6.4	372.778	70	68.8994
13	2907	0.15	20	20.3	5.4	14.9	258.333	46	41.7006
14	2927	0.05	7	12.7	7.2	5.5	315.556	60	66.3113
15	2928	0.07	12	16.5	10.4	6.1	327.778	60	63.7460
16	2984	0.41	.	25.4	8.1	17.3	318.889	45	.
17	2985	0.20	24	25.7	13.6	12.1	301.667	47	.
18	2993	0.13	49	43.0	23.4	24.6	272.222	28	30.6091
19	3064	0.01	6	9.8	2.5	7.3	245.000	55	49.2799
20	3095	0.10	52	51.4	28.4	23.0	292.222	39	32.5309
21	3100	0.15	20	20.3	5.4	14.9	258.333	55	41.7006
22	3101	0.45	22	26.6	11.2	15.4	327.778	57	45.0228
23	3157	0.32	.	21.9	8.4	13.5	322.222	46	43.7050
24	3158	0.14	.	14.6	5.0	9.6	297.778	50	53.8228
25	3164	0.22	17	24.4	8.7	15.7	276.111	39	41.0529
26	3166	0.18	23	21.7	5.9	15.8	292.222	47	43.5694
27	3167	0.21	17	25.1	13.5	11.6	298.889	47	47.9598
28	3169	0.29	17	23.6	9.0	14.6	318.889	41	43.7685
29	3178	0.09	.	26.9	10.6	16.3	312.778	47	46.5556
30	3179	.	.	24.0	10.4	13.6	303.333	47	.
31	3180	0.03	.	19.5	8.5	11.0	318.889	49	48.4081
32	3181	0.20	.	20.1	8.5	11.6	333.333	47	49.4711
33	3198	0.51	35	26.6	11.0	15.6	331.111	48	50.8742
34	3213	0.51	12	16.5	10.4	6.1	327.778	60	63.7460
35	3215	0.01	29	20.4	.	.	.	.	.
36	3302	0.55	.	20.1	8.5	11.6	333.333	47	49.4711
37	3303	0.56	.	20.1	8.5	11.6	333.333	47	49.4711
38	3307	0.56	.	20.1	8.5	11.6	333.333	47	49.4711
39	3319	0.38	27	21.4	.	.	.	.	.

Preliminary

REGRESSION OF CUMMINS NTC 290 WEIGHTED PARTICULATE EMISSIONS
VERSUS SELECTED FUEL PROPERTIES
REFERENCE: SAE PAPER NO. 841364

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE WTOKWA

WARNING: 10 OBSERVATIONS DELETED DUE TO MISSING VALUES.

STEP 1 VARIABLE SA ENTERED R SQUARE = 0.74641108
C(P) = 75.27211162

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.36853890	0.36853890	100.08	0.0001
ERROR	34	0.12520900	0.00368262		
TOTAL	35	0.49374790			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.22710568				
SA	0.58380602	0.05835965	0.36853890	100.08	0.0001

BOUNDS ON CONDITION NUMBER: 1. 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE MSMULTI ENTERED R SQUARE = 0.92098209
C(P) = 3.42582145

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.45473297	0.22736649	192.31	0.0001
ERROR	33	0.03901493	0.00118227		
TOTAL	35	0.49374790			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.18116651				
SA	0.51509743	0.03403134	0.27085543	229.10	0.0001
MSMULTI	0.00484304	0.00056720	0.09619407	72.91	0.0001

BOUNDS ON CONDITION NUMBER: 1.059223 4.236892

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

Preliminary

REGRESSION OF CUMMINS NTC 290 WEIGHTED PARTICULATE EMISSIONS
VERSUS SELECTED FUEL PROPERTIES
REFERENCE: SAE PAPER NO. 841364

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE WTDKWA

STEP 3 VARIABLE D8690CA ENTERED R SQUARE = 0.92450159
C(P) = 3.81011425

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.45661884	0.15220628	131.15	0.0001
ERROR	32	0.03712906	0.00116025		
TOTAL	35	0.49374790			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.10011102				
SA	0.49305214	0.03738935	0.19647868	169.34	0.0001
MSMULTI	0.00461162	0.00059049	0.07076941	60.99	0.0001
D8690CA	0.00028759	0.00022558	0.00188587	1.63	0.2115

BOUNDS ON CONDITION NUMBER: 1.472197, 11.93948

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE MSMONO ENTERED R SQUARE = 0.92671668
C(P) = 5.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.45756441	0.11439110	95.00	0.0001
ERROR	31	0.03613349	0.00116721		
TOTAL	35	0.49374790			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.05691744				
SA	0.48549941	0.03933742	0.18950950	162.36	0.0001
MSMULTI	0.00437782	0.00064671	0.05348640	45.83	0.0001
MSMONO	0.00114467	0.00127199	0.00094557	0.81	0.3750
D8690CA	0.00038995	0.00025323	0.00276789	2.37	0.1337

BOUNDS ON CONDITION NUMBER: 1.844137, 23.77502

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

Preliminary

AVERAGED FUEL PROPERTY DATA FOR THE CRC VE-1 PROGRAM FUELS 1

6:57 WEDNESDAY, AUGUST 3, 1988

OBS	FUEL	SULFUR	CERBAC	CERBAH	FIAAROM	FIAOLEF	FIAPARA	MSPARA	MSNAPH	MSAROM	MSMONO	MSDI	MSTRI	MSMULTI	AROMC
1	1	0.302	85.7	13.9	16.6	1.0	83.4	47.0	36.8	16.1	11.9	3.9	0.3	4.2	10.0
2	2	0.297	87.3	11.8	43.9	2.0	56.1	29.3	24.8	45.1	18.4	25.5	1.2	26.7	31.0
3	3	0.299	86.7	12.0	46.9	3.0	53.1	28.2	26.7	43.2	19.0	22.3	1.9	24.2	27.0
4	4	0.291	86.1	13.8	19.0	1.0	81.0	51.7	31.9	16.0	8.3	6.9	0.9	7.7	9.3
5	5	0.286	86.7	13.0	33.6	2.0	66.4	27.3	46.8	25.7	17.9	6.9	0.9	7.8	13.0
6	6	0.051	86.7	13.0	33.6	2.0	66.4	27.3	46.8	25.7	17.9	6.9	0.9	7.8	13.0
7	7	0.164	86.7	13.0	33.6	2.0	66.4	27.3	46.8	25.7	17.9	6.9	0.9	7.8	13.0
8	8	0.040	86.4	14.1	11.1	0.4	83.9	40.9	50.1	9.0	8.4	0.4	0.2	0.6	5.0
9	9	0.057	87.3	12.5	42.9	0.6	57.1	32.7	25.9	41.1	27.1	13.1	0.9	14.0	23.0

OBS	TIBP	T05	T10	T50	T90	T95	TEP	API	RELDENS	CETANE	CCI	VIS104F	VIS212F	ANILINE	SMOKEPT
1	312	338	347	424	549	579	607	43.6	0.8031	51.0	49.5	1.56	0.78	149	21.3
2	318	350	365	461	559	587	617	32.6	0.8623	35.0	35.3	1.74	0.82	102	10.1
3	396	451	470	540	633	658	675	29.4	0.8794	43.0	41.2	3.28	1.28	130	10.1
4	373	449	478	558	636	662	676	33.6	0.8319	56.0	62.6	3.68	1.41	176	21.3
5	336	385	409	511	602	625	642	34.8	0.8509	44.3	45.7	2.68	1.12	142	15.2
6	336	385	409	511	602	625	642	34.8	0.8509	44.3	45.7	2.68	1.12	142	15.2
7	336	385	409	511	602	625	642	34.8	0.8509	44.3	45.7	2.68	1.12	142	15.2
8	339	371	386	436	602	632	656	40.1	0.8246	54.0	52.8	2.35	1.03	164	27.5
9	340	379	400	497	605	633	656	32.3	0.8639	39.0	39.9	2.36	1.02	121	11.5

Preliminary

REGRESSIONS OF DDC 60-11-315 WEIGHTED EMISSIONS DATA
6:50 WEDNESDAY, AUGUST 3, 1988

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE TRBSP

WARNING: 3 OBSERVATIONS DELETED DUE TO MISSING VALUES.

STEP 1 VARIABLE SULFUR ENTERED R SQUARE = 0.64900674
C(P) = 27.86577250

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.03240265	0.03240265	55.47	0.0001
ERROR	30	0.01752388	0.00058413		
TOTAL	31	0.04992653			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.22099650				
SULFUR	0.30347983	0.04074685	0.03240265	55.47	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE MSMULTI ENTERED R SQUARE = 0.82803670
C(P) = 1.37050510

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.04134100	0.02067050	69.52	0.0001
ERROR	29	0.00858553	0.00029605		
TOTAL	31	0.04992653			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.20820497				
SULFUR	0.24534053	0.03087792	0.01869010	63.13	0.0001
MSMULTI	0.00210390	0.00038290	0.00893834	30.19	0.0001

BOUNDS ON CONDITION NUMBER: 1.133047, 4.532187

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

Preliminary

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE TRBSP

STEP 3 VARIABLE MSMONO ENTERED R SQUARE = 0.83034789
C(P) = 3.00264525

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.04145639	0.01381880	45.68	0.0001
ERROR	28	0.00847014	0.00030251		
TOTAL	31	0.04992653			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.21647630				
SULFUR	0.23610728	0.03460816	0.01407973	46.54	0.0001
MSMULTI	0.00226143	0.00046353	0.00720016	23.80	0.0001
MSMONO	-0.00047705	0.00077241	0.00011539	0.38	0.5418

BOUNDS ON CONDITION NUMBER: 1.625092, 13.57486

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE TPOC ENTERED R SQUARE = 0.83036451
C(P) = 5.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.04145722	0.01036430	33.04	0.0001
ERROR	27	0.00846931	0.00031362		
TOTAL	31	0.04992653			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.21253920				
SULFUR	0.23623219	0.03532505	0.01402803	44.72	0.0001
MSMULTI	0.00226905	0.00049472	0.00659872	21.04	0.0001
MSMONO	-0.00047773	0.00078466	0.00011568	0.37	0.5487
TPOC	0.00001232	0.00023764	0.00000033	0.00	0.9594

BOUNDS ON CONDITION NUMBER: 1.785182, 23.50077

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

Preliminary

REGRESSIONS OF DDC 60-11-315 S-2 EMISSIONS DATA
6:50 WEDNESDAY, AUGUST 3, 1988

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE S2BSP

WARNING: 1 OBSERVATIONS DELETED DUE TO MISSING VALUES.

STEP 1 VARIABLE SULFUR ENTERED R SQUARE = 0.38321443
C(P) = 12.41111221

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.04818860	0.04818860	18.02	0.0002
ERROR	29	0.07755979	0.00267448		
TOTAL	30	0.12574839			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.22868240				
SULFUR	0.37297489	0.08786720	0.04818860	18.02	0.0002

BOUNDS ON CONDITION NUMBER: 1. 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE MSMULTI ENTERED R SQUARE = 0.53401418
C(P) = 4.77537135

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.06715142	0.03357571	16.04	0.0001
ERROR	28	0.05859696	0.00209275		
TOTAL	30	0.12574839			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.20650753				
SULFUR	0.30725974	0.08073359	0.03031237	14.48	0.0007
MSMULTI	0.00328364	0.00109251	0.01896283	9.06	0.0055

BOUNDS ON CONDITION NUMBER: 1.073883, 4.315554

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

Preliminary

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE S25SP

STEP 3 VARIABLE MSMONO ENTERED R SQUARE = 0.58825556
C(P) = 3.30947791

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.07397219	0.02465740	12.86	0.0001
ERROR	27	0.05177620	0.00191764		
TOTAL	30	0.12574839			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.27202566				
SULFUR	0.24211369	0.03465053	0.01568721	8.18	0.0091
MSMULTI	0.00459187	0.00125347	0.02573446	13.42	0.0011
MSMONO	-0.00381149	0.00202099	0.00682077	3.56	0.0701

BOUNDS ON CONDITION NUMBER: 1.549921, 13.0758

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE T90C ENTERED R SQUARE = 0.59309891
C(P) = 5.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.07458123	0.01864531	9.47	0.0001
ERROR	26	0.05116716	0.00196797		
TOTAL	30	0.12574839			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.16646294				
SULFUR	0.24859969	0.05654315	0.01623979	8.25	0.0080
MSMULTI	0.00470231	0.00128524	0.02634335	13.39	0.0011
MSMONO	-0.00391502	0.00205577	0.00713736	3.63	0.0680
T90C	0.00033430	0.00060092	0.00060904	0.31	0.5828

BOUNDS ON CONDITION NUMBER: 1.587807, 22.0461

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

Preliminary

REGRESSIONS OF NTCC 400 S-2 EMISSIONS DATA
6:53 WEDNESDAY, AUGUST 3, 1988

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE S2BSP

STEP 1 VARIABLE MSMULTI ENTERED R SQUARE = 0.83369830
C(P) = 32.45270264

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.15740224	0.15740224	115.30	0.0001
ERROR	23	0.03139776	0.00136512		
TOTAL	24	0.18880000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.48162466				
MSMULTI	0.01096559	0.00102120	0.15740224	115.30	0.0001

BOUNDS ON CONDITION NUMBER: 1. 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE T90C ENTERED R SQUARE = 0.87755848
C(P) = 20.35516204

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.16568304	0.08284152	78.84	0.0001
ERROR	22	0.02311696	0.00105077		
TOTAL	24	0.18880000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.03576675				
MSMULTI	0.01103767	0.00089631	0.15934751	151.65	0.0001
T90C	0.00141158	0.00050203	0.00828030	7.88	0.0103

BOUNDS ON CONDITION NUMBER: 1.000821 4.003235

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE SULFUR ENTERED R SQUARE = 0.92735699
C(P) = 6.34892006

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.17508500	0.05836167	89.36	0.0001
ERROR	21	0.01371500	0.00065310		
TOTAL	24	0.18880000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.05137069				
SULFUR	0.19629810	0.05173627	0.00940196	14.40	0.0011
MSMULTI	0.01025392	0.00073620	0.12669503	193.99	0.0001
T90C	0.00157454	0.00039874	0.01018359	15.59	0.0007

BOUNDS ON CONDITION NUMBER: 1.099087 9.594001

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Preliminary

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE S2BSP

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEP 4 VARIABLE MSMONO ENTERED R SQUARE = 0.93777613
C(P) = 5.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.17705213	0.04426303	75.36	0.0001
ERROR	20	0.01174787	0.00058739		
TOTAL	24	0.18880000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.09173008				
SULFUR	0.22616337	0.05170788	0.01123725	19.13	0.0003
MSMULTI	0.00941825	0.00083427	0.07486204	127.45	0.0001
MSMONO	0.00222619	0.00121650	0.00196713	3.35	0.0822
T90C	0.00159027	0.00037525	0.01039271	17.68	0.0004

BOUNDS ON CONDITION NUMBER: 1.551052, 20.94697

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

Preliminary

El Segundo Refinery Diesel Hydrotreater
Twenty-two component hydrocarbon type analysis

Run No: H26358 Acquired at 11:11 on 06/28/88
Ser No: 8070691 Analyzed at 9:15 On 06/29/88
Sample: D-4360 Feed MB LONG, X2007
Conds.: MULT425, MAG1160, SM205, HV401+55, REP39
Submitted by: MB LONG Analyst: AMGI Acct. No.: 3154

C(n)H(2n+2)	Parrafins	25.5	
C(n)H(2n)	Monocycloparaffins	22.8	
C(n)H(2n-2)	Dicycloparaffins	13.8	
C(n)H(2n-4)	Tricycloparaffins	8.0	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		44.6
	Saturates		70.1
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	6.0	
C(n)H(2n-8)	Benzocycloparaffins	4.3	
C(n)H(2n-10)	Benzodicycloparaffins	3.8	
Diaromatics			
C(n)H(2n-12)	Naphthalenes	5.8	
C(n)H(2n-14)		3.3	
C(n)H(2n-16)		3.6	
Triaromatics			
C(n)H(2n-18)		1.1	
C(n)H(2n-22)		0.0	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		27.8
C(n)H(2n-4)S	Thiophenes	0.3	
C(n)H(2n-10)S	Benzothiophenes	1.8	
C(n)H(2n-16)S	Dibenzothiophenes	0.0	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		2.1

Calculated %C= 86.7 %H= 13.0 %Thiophenic S= 0.3

PLEASE NOTE--
Sample types correctly analyzed:
1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.
Factors which contribute to an incorrect analysis:
1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

El Segundo Refinery Diesel Hydrotreater

Twenty-two component hydrocarbon type analysis

Run No: H26359 Acquired at 11:30 on 06/28/88
Ser No: 8070698 Analyzed at 9:17 On 06/29/88
Sample: D-4361 Product MB LONG, X2007
Conds.: MULT425, MAG1160, SM205, HV401+55, REP39
Submitted by: MB LONG Analyst: AMGI Acct. No.: 3154

C(n)H(2n+2)	Parrafins	30.0	
C(n)H(2n)	Monocycloparaffins	25.5	
C(n)H(2n-2)	Dicycloparaffins	13.5	
C(n)H(2n-4)	Tricycloparaffins	6.8	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		45.8
	Saturates		75.8
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	8.0	
C(n)H(2n-8)	Benzocycloparaffins	5.9	
C(n)H(2n-10)	Benzodicycloparaffins	2.1	
Diaromatics			
C(n)H(2n-12)	Naphthalenes	3.8	
C(n)H(2n-14)		1.7	
C(n)H(2n-16)		1.8	
Triaromatics			
C(n)H(2n-18)		0.6	
C(n)H(2n-22)		0.0	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		23.9
C(n)H(2n-4)S	Thiophenes	0.0	
C(n)H(2n-10)S	Benzothiophenes	0.3	
C(n)H(2n-16)S	Dibenzothiophenes	0.0	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		0.3

Calculated %C= 86.6 %H= 13.4 %Thiophenic S= 0.0

PLEASE NOTE--

Sample types correctly analyzed:

1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.

Factors which contribute to an incorrect analysis:

1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

Richmond Refinery Mid-Distillate Hydrotreater

Twenty-two component hydrocarbon type analysis

Run No: H25634 Acquired at 13.25 on 10/12/87
Ser No: 7091730 Analyzed at 8:33 On 10/13/87
Sample: 3460 MDH REACTOR FEED TH GOUW, X2417
Conds.: MULT400, MAG1155, SM205, HV401+62, REF99
Submitted by: TH GOUW Analyst: AMGJ Acct. No.: 62145

C(n)H(2n+2)	Parrafins	17.3	
C(n)H(2n)	Monocycloparaffins	28.3	
C(n)H(2n-2)	Dicycloparaffins	21.7	
C(n)H(2n-4)	Tricycloparaffins	9.2	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		59.1
	Saturates		76.4
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	6.1	
C(n)H(2n-8)	Benzocycloparaffins	3.7	
C(n)H(2n-10)	Benzodicycloparaffins	2.1	
Diaromatics			
C(n)H(2n-12)	Naphthalenes	4.7	
C(n)H(2n-14)		2.3	
C(n)H(2n-16)		2.0	
Triaromatics			
C(n)H(2n-18)		[illegible]	
C(n)H(2n-22)		0.2	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		22.0
C(n)H(2n-4)S	Thiophenes	0.1	
C(n)H(2n-10)S	Benzothiophenes	1.0	
C(n)H(2n-16)S	Dibenzothiophenes	0.5	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		1.6

Calculated %C= 86.8 %H= 12.9 %Thiophenic S= 0.3

PLEASE NOTE--
Sample types correctly analyzed:
1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.
Factors which contribute to an incorrect analysis:
1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

Richmond Refinery Mid-Distillate Hydrotreater

Twenty-two component hydrocarbon type analysis

Run No: H25635 Acquired at 13:50 on 10/12/87
Ser No: 7091718 Analyzed at 8:30 On 10/13/87
Sample: 3460 MDH REACTOR EFFLUENT TH GOUW, X2417
Conds: MULT400, MAG1155, SM205, HV401+62, RFP99
Submitted by TH GOUW Analyst: AMGI Acct. No.: 62145

C(n)H(2n+2)	Parrafins	17.8	
C(n)H(2n)	Monocycloparaffins	29.7	
C(n)H(2n-2)	Dicycloparaffins	22.8	
C(n)H(2n-4)	Tricycloparaffins	9.0	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		61.5
	Saturates		79.3
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	6.9	
C(n)H(2n-8)	Benzocycloparaffins	4.8	
C(n)H(2n-10)	Benzodicycloparaffins	2.1	
Diaromatics			
C(n)H(2n-12)	Naphtholenes	3.0	
C(n)H(2n-14)		1.6	
C(n)H(2n-16)		1.5	
Triaromatics			
C(n)H(2n-18)		0.0	
C(n)H(2n-22)		0.0	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		19.9
C(n)H(2n-4)S	Thiophenes	0.0	
C(n)H(2n-10)S	Benzothiophenes	0.3	
C(n)H(2n-16)S	Dibenzothiophenes	0.5	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		0.8

Calculated %C= 86.6 %H= 13.2 %Thiophenic S= 0.2

PLEASE NOTE--

Sample types correctly analyzed:

1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.

Factors which contribute to an incorrect analysis:

1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

El Segundo Diesel Hydrotreater

Twenty-two component hydrocarbon type analysis

Run No: H25442 Acquired at 12:57 on 09/01/87
Ser No: CH Analyzed at 13.14 On 09/01/87
Sample: 3395 DIESEL PRODUCT T H GOUW
Conds.: MULT370, MAG1038, SM205, HV401+62, REP183
Submitted by: GOUW Analyst: PAZZI Acct. No.: 62145

C(n)H(2n+2)	Parrafins	35.8	
C(n)H(2n)	Monocycloparaffins	24.3	
C(n)H(2n-2)	Dicycloparaffins	14.6	
C(n)H(2n-4)	Tricycloparaffins	6.5	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		45.4
	Saturates		81.2
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	6.3	
C(n)H(2n-8)	Benzocycloparaffins	4.9	
C(n)H(2n-10)	Benzodicycloparaffins	1.5	
Diaromatics			
C(n)H(2n-12)	Naphthalenes	2.7	
C(n)H(2n-14)		1.3	
C(n)H(2n-16)		1.4	
Triaromatics			
C(n)H(2n-18)		0.5	
C(n)H(2n-22)		0.0	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		18.6
C(n)H(2n-4)S	Thiophenes	0.0	
C(n)H(2n-10)S	Benzothiophenes	0.2	
C(n)H(2n-16)S	Dibenzothiophenes	0.0	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		0.2

Calculated %C= 86.4 %H= 13.6 %Thiophenic S= 0.0

PLEASE NOTE--

Sample types correctly analyzed:
1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.

Factors which contribute to an incorrect analysis:
1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

El Segundo Diesel Hydrotreater

Twenty-two component hydrocarbon type analysis

Run No: H25443
Ser No: CH
Sample: 3395 DIESEL FEED
Conds.: MULT370, MAG1038, SM205, HV401+62, REP183
Submitted by: GOUW

Acquired at 13.24 on 09/01/87
Analyzed at 13.44 On 09/01/87
T H GOUW
Analyst: PAZZI

Acct. No.: 62145

C(n)H(2n+2)	Parrafins	31.8	
C(n)H(2n)	Monocycloparaffins	22.7	
C(n)H(2n-2)	Dicycloparaffins	16.1	
C(n)H(2n-4)	Tricycloparaffins	8.5	
C(n)H(2n-6)	Tetracycloparaffins	0.0	
C(n)H(2n-8)	Pentacycloparaffins	0.0	
C(n)H(2n-10)	Hexacycloparaffins	0.0	
C(n)H(2n-12)	Heptacycloparaffins	0.0	
	Total Naphthenes		47.3
	Saturates		79.1
Monoaromatics			
C(n)H(2n-6)	Alkylbenzenes	4.1	
C(n)H(2n-8)	Benzocycloparaffins	3.5	
C(n)H(2n-10)	Benzodicycloparaffins	2.7	
Diaromatics			
C(n)H(2n-12)	Naphthalenes	3.8	
C(n)H(2n-14)		2.1	
C(n)H(2n-16)		2.2	
Triaromatics			
C(n)H(2n-18)		0.7	
C(n)H(2n-22)		0.1	
Tetraaromatics			
C(n)H(2n-24)		0.0	
C(n)H(2n-28)		0.0	
	Aromatics		19.1
C(n)H(2n-4)S	Thiophenes	0.4	
C(n)H(2n-10)S	Benzothiophenes	1.5	
C(n)H(2n-16)S	Dibenzothiophenes	0.0	
C(n)H(2n-22)S	Naphthobenzothiophenes	0.0	
	Sulfur compounds		1.8

Calculated %C= 86.4 %H= 13.3 %Thiophenic S= 0.3

PLEASE NOTE--

Sample types correctly analyzed:

1. C12 to C36, 250 Deg F to 1050 Deg F hydrocarbons.
2. Olefin-free hydrocarbons.
3. Less than 5% oxygen, nitrogen, or sulfur compounds.

Only listed types are considered; all others are ignored.

Factors which contribute to an incorrect analysis:

1. Large amounts of a single hydrocarbon.
2. Unusual distribution of compounds.
3. Thermally unstable materials.

Preliminary

COMMENTS ON REDUCING DIESEL AROMATICS PORTION OF ARTHUR D. LITTLE MOTOR VEHICLE FUELS STUDY

D. J. Youngblood
Texaco Refining and Marketing Inc.
August 5, 1988

In July of 1988 refining industry representatives were provided with copies of a three volume draft final report prepared by Arthur D. Little, Inc. (ADL) for the California Air Resources Board (CARB) entitled "Cost of Reducing Aromatics and Sulfur Levels in Motor Vehicle Fuels." A review of the portion of this study dealing with reducing diesel fuel aromatics content in California is discussed herein. Although many details of this study were not provided by ADL making analysis difficult, sufficient information was presented to determine that this study is seriously flawed and greatly underestimates the investment requirements and hence cost for reducing diesel aromatics. A more detailed analysis could be made if additional information had been provided by ADL. CARB recognized the lack of adequate explanation and documentation of this study in comments to ADL on July 7, 1988.

In reviewing the A. D. Little study, the following areas were examined:

1. Use of unproven technology for diesel fuel aromatics reduction and its probable impact on investment cost estimates and construction time.

2. Apparent errors in properly sizing processing units in the ADL study resulting in greatly underestimating process unit investment costs due to economy of scale effects.

3. Apparent errors in seriously underestimating new processing unit hydrogen requirements and its impact on investment costs.

4. Failure to escalate investment costs from 1987 to mid-construction date resulting in further underestimating construction costs.

5. Apparent low operating costs for new units.

6. The combined effects of the above items on the estimated cost for dearomatization.

Based on an examination of the above factors, it appears that the A. D. Little study greatly underestimated the investment requirements and total cost of diesel aromatics as summarized below:

ADL CASE	TOTAL INVESTMENT, MILLION $		TOTAL COST, ¢/GAL DIESEL	
	BASIS ADL	ADJUSTED ADL	BASIS ADL	ADJUSTED ADL
20% Aromatics/0.14% Sulfur	410.2	1446.8	3.8	11.7
10% Aromatics/0.05% Sulfur	1431.1	3320.3	27.6	40.6
10% Arom/0.05% NPRA Sep.	1011.5	2346.8	21.8	31.1

The above adjustments are explained in more detail in the following section of this analysis.

In their study, ADL indicates that diesel aromatics have been gradually increasing and are expected to continue to increase in the future unless controlled. The average aromatics content of California diesel fuel has not been increasing basis the Southwest Research Institute Diesel Survey which is conducted twice a year for the petroleum industry. For the period from July of 1982 to January of 1985 the average aromatics of California highway diesel was 30.1% which was essentially the same as the 30.0% average for the period of July 1985 through January 1988. Also basis the A. D. Little study diesel aromatics was 30.9% in 1986 and is projected to be 30.7% in 1991 and 31.0% in 1995. Thus, an increase in the future is not projected.

Instead of passing regulations to reduce aromatics which would be extremely expensive and not cost effective, the California Air Resources Board should consider following the much more cost effective recommendations contained in the joint proposal made to the EPA on July 19, 1988 by representatives of the oil industry and engine manufacturers. This proposal suggests that aromatics be capped at present levels by employing a 40 minimum Cetane Index.[1]

Diesel Aromatics Reduction Technology

Industry experts and refiners agree that hydroprocessing would be the technology used if diesel aromatic reduction is required. Existing diesel hydrotreaters do not significantly reduce total aromatics. These hydrotreaters typically operate at 400 - 700 psig and at liquid hour space velocities above 2.0.[2] Even when a diesel hydrotreater is designed for much higher pressures and lower space velocities, little aromatics reduction is achieved. For example, a commercial Texaco diesel hydrotreater

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[1]Also reference paper by D. J. Youngblood, "Capping Highway Diesel Aromatics Content," July 1988.

[2]Liquid hourly space velocity equals barrels per hour charge/barrels catalyst in reactors. The lower the value the more severe the operations.

that operates at 1050 psig and a liquid hourly space velocity of 1.0 using a nickel-moly catalyst only achieves a 7.5% total aromatics reduction charging a mixture of diesel boiling range virgin gas oil, light cycle catalytic cracker gas oil and coker gas oil.

With about a 30% average aromatic content for California diesel fuels, most refineries would need to achieve over a 30% reduction of the total diesel pool to meet a 20 vol. percent aromatics specification. Presently there are no commercial hydroprocessing units designed to produce 20% or lower aromatics diesel by dearomatization.

Because of a lack of commercial experience in reducing aromatics, refineries will need extensive research employing pilot unit studies to design new dearomatization units for their specific feed stocks. Decisions will have to be made on the best process for achieving dearomatization and desulfurization. A number of catalyst options are technically feasible. Generally, catalysts that are good for dearomatization are sensitive to sulfur poisoning and must be used in a two stage process with severe sulfur reduction in the first stage to protect the second stage dearomatization catalyst. It is also possible to achieve dearomatization in a single stage with a less sulfur sensitive catalyst operating at much higher pressures. Establishing the best system for a specific refinery will require extensive work and time. The lower the aromatics reduction target, the more difficult it will be to develop the necessary process technology.

Product quality impacts will also have to be checked in pilot unit studies. Severe hydrotreating can adversely affect diesel quality by increasing corrosivity, decreasing lubricity, decreasing conductivity, increasing gum formation tendency and lowering color stability. These side effects could cause performance and durability problems in diesel engines.

Arthur D. Little selected the UOP AH Unibon process to dearomatize diesel using an estimate obtained from UOP in September of 1987. This process is a two-stage process. The first stage uses a high pressure hydrotreating catalyst to reduce sulfur, nitrogen and oxygen to very low levels and provide feed to the second stage which contains a noble metal (platinum) catalyst used for dearomitization. Although noble metal catalysts are good dearomitization catalysts, they are very easily poisoned and hence must be protected by severe hydrotreatment of the feed to them. Although the UOP AH Unibon process has been used commercially for dearomatizating kerosine, it has never been commercially used for heavier diesel boiling range materials. Further, it has never been demonstrated even in pilot unit runs by UOP to be suitable for light catalytic cycle gas oil even though UOP provided ADL with an estimate for this

feed assuming that a very high 71.4% dearomatization could be achieved.

In furnishing their estimate to ADL, UOP indicated that (1) they believed the UOP AH Unibon process was suitable for this type service but were not aware of any commercial operations in this region and (2) pilot plant optimization studies would be required to establish a firm design basis for an actual project.

Such pilot unit studies would be used to determine if predicted operating conditions would achieve the projected effects or if not, what conditions would be required. They also would be employed to determine the aging rate of the catalyst and if additional design modifications would be required to protect the sensitive noble metal catalyst from poisoning so that run length of at least one and preferably two or more years could be achieved.

What are the implications of using new commercially (and even pilot unit) unproven technology on the potential cost and time of construction of such a process? In answering the question on investment cost impact, there is a study made by the Rand Corporation for the U.S. Department of Energy which can be used. This study entitled "Understanding Cost Growth and Performance Short Falls in Pioneer Process Plants" was published in 1981 and followed by a publication in June 1983 entitled "Pioneer Plants Study User's Manual" which provides a method of estimating both cost misestimation and plant performance of new technology processes. The pioneer plants study statistically analyzed 44 pioneer (or new technology) process plants that were commercialized and found that capital cost are repeatedly underestimated and their performance falls short of what was predicted. For the 11 refinery projects in this study, the average investment cost was 63% higher than estimated. Thus, there is a high probability that the investment costs of the UOP AH Unibon process and Mobil processes (which make low aromatic distillates) used in the ADL study are underestimated.

Recognizing this potential basis past experience, extensive pilot unit studies are needed including aging rate studies to develop more reliable cost estimates for the UOP process or other dearomatization processes. This could easily result in a one-year delay in start of project construction due to time needed for pilot studies. A large number of refineries seeking the same information at about the same time for different feed stocks could lead to additional delays in completion of pilot unit studies.

Total construction time would also be adversely impacted by overloading industry construction capabilities due to the large number of units needing construction at the same time if aromatics regulations are promulgated. Limitations probably

would be encountered in alloy steel supply, reactor shop availability, compressor shop availability, exchanger shop availability, design engineering manpower and construction manpower. These limitations could add up to a years delay in project construction and would escalate construction costs. Taking all of these factors into consideration, including time for pilot unit studies, would probably lead to over a 4 year time requirement following project approval to complete construction. Even if regulations were promulgated at the end of 1988 or early 1989, start-up would probably not occur until 1993 or later. By this time federal EPA regulations recommended by the oil industry and engine manufacturers, if enacted, would negate any small benefit that might be achieved by aromatics reduction.

Although the Mobil processes were not analyzed in a manner similar to the UOP AH Unibon process, they have not been commercialized and are thus subject to the same potential for cost underestimating, underperformance and construction delays as the UOP process.

Process Unit Sizing Impact on Investment

To analyze the ADL investment cost requirements, Table I was constructed for the 20% aromatics/0.14% sulfur diesel case. The upper section of this table shows ADL data including an investment cost of $410.2 million. The estimated process investments shown in this section were developed in our analysis by using individual unit capacities and scale factors provided by ADL. In making these estimates, it was assumed that the capacity of process units for each refinery group was that of the entire group (i.e., only one new unit constructed in each group instead of one for each refinery in each group as should be the case). Using this procedure, the estimated investment cost was within 3.4% of the ADL estimate. This strongly suggests that ADL did not reduce their unit capacities in each refinery group to account for the fact that multiple refineries exist in each group. This would be a serious error since the cost of several units of smaller capacity is much more expensive than a single unit of the same capacity due to economy of scale effects on cost.

The B section of Table I adjusts for the fact that separate smaller units would be built in each refinery in each group instead of only one unit per group. In this case the estimated cost is about 1.8 times greater than the single unit/group approach apparently used by ADL. In checking the 15% and 10% diesel aromatics cases it appears that ADL made the same error and thus substantially underestimated their investment cost also.

Hydrogen Requirements

Although ADL did not provide details on their hydrogen balance calculations, they did provide information on the total new hydrogen generation capacity required by each refinery group for each case study. For the 20% aromatics/0.14% sulfur diesel 1991 case, no new hydrogen generation capacity is indicated to be needed. This differs markedly from results in the 1986 NPRA diesel survey which indicates for the 20% aromatics/0.05% sulfur case, 109 million SCF/day of new capacity is needed in California.

To check hydrogen consumption requirements for the ADL 20% aromatics/0.14% sulfur case, Table II was constructed using hydrogen consumption numbers for individual processing units provided by ADL. As shown, over 150 million SCF/day of hydrogen is required. If it is assumed that 30% of this is supplied by existing "excess" hydrogen in the refineries, then the new hydrogen generation capacity equals that of the NPRA survey for California. This figure is much more likely than the zero value developed by ADL.

Table III is similar to Table II except it provides a hydrogen consumption balance for the 10% aromatics/0.05% sulfur 1991 ADL case. Total new processing hydrogen needs amount to over 350 million SCF/day with net needs for new capacity estimated at 308 million SCF/day compared to only 105 million SCF/day shown by ADL. Also, the ADL results are odd in that all of their new hydrogen generation capacity is in refinery groups I and II.

If the ADL investment requirements are adjusted for proper unit size and more realistic new hydrogen generation requirements, results are obtained as follows:

CASE	TOTAL INVESTMENTAL, MILLIONS $		
	ADL	TEXACO ADJUSTED ADL	% ADJUSTED OVER ADL
20% aromatics	410.2	964.5	135%
10% aromatics	1431.1	2213.5	55%

Tables IV and V give more details on the adjustments to the ADL results. As discussed previously the adjustments were made to better account for unit size and new hydrogen generation requirements.

For the 20% aromatics diesel case, additional investment would also be required to meet a 0.05% sulfur diesel specification. The ADL investment cost estimates for reducing aromatics in diesel are much too low.

Investment Cost Escalation

All investment costs shown by ADL in their study appear to be 1987 costs without escalation to mid-construction. Assuming construction is completed in late 1993 with a mid-construction time or early 1992, the construction cost multiplier could range from 1.3 to 1.7 with the higher number being more likely because it represented heavy construction industry activity which would probably exist. Since ADL apparently did not escalate investment costs from 1987 to mid-construction (as indicated by the matching investment calculations in Table I section A), again investment costs would be underestimated.

Operating Costs for New Investments

Table VI, attached, presents a comparison of operating costs as a percent of capital cost for the ADL Study and the 1986 NPRA Diesel Survey for California. As shown the ADL operating costs are only about 60% of the NPRA operating costs. Part of this lower operating cost may be related to the fact that the ADL Study did not consider costs related to auxiliary equipment such as sulfur recover facilities, sour water strippers, amine recovery and tankage. Also, as discussed previously, it appears that ADL used only one process unit/refinery group instead of one process unit/refinery in each refinery group. The proper use of all refineries would have resulted in smaller processing units which in turn would have increased operating costs. Several smaller processing units with the same total capacity as a larger unit will have higher operating expenses/barrel of capacity. Thus, it appears that ADL underestimated operating costs.

Combined Effects of Cost Underestimating

From the preceding review, it appears the ADL seriously underestimated the cost of dearomatization. To look at the combined effect of possible errors on costs, Table VII was constructed. Accounting for these possible errors could raise the cost for the 20% aromatics/0.14% sulfur case from 3.8 to 11.7 ¢/gal of total diesel or by a factor of three. Although this adjusted cost is higher than the 8.1 ¢/gal price developed for California in the 1986 NPRA survey for 20% aromatics/0.05% sulfur diesel, aromatics reduction costs were probably understated in the NPRA survey as discussed in section E of Attachment A. This attachment provides an in-house estimate of the cost of dearomatizing diesel from 37% to 20% for a specific refinery. This refinery's dearomatization unit would be significantly larger than that of the average California refinery and hence would benefit from economy of scale. Its total cost was of 11.4 ¢/gal of total diesel as shown in Attachment A.

For the 10% aromatics/0.05% sulfur case the cost could increase from 27.6 to 40.6 ¢/gal of total diesel or by a factor of almost

1.5. These cost increases do not include the possible 63% increase in investment for the UOP AH Unibon and Mobil processes indicated from the previously referenced Rand study. Basis the above, the ADL study is seriously flawed and greatly underestimates the cost of diesel aromatics reduction. Thus, this study should not be used to estimate the cost of dearomatizing diesel for regulatory purposes. Although other areas of the ADL study were not examined, it would be expected that some of the problems uncovered in examining the aromatics area would apply to other areas.

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Table I

INVESTMENT COST ANALYSIS FOR 20% AMOMATICS/0.14% SULFUR 1991 A. D. LITTLE CASE

A. AS REPORTED BY A. D. LITTLE

REFINERY GROUP	NO. REFINERIES	DIESEL, 000 B/D	PROCESS ADDITIONS, 000 B/D					ESTIMATED PROCESS INVEST., MIL. $*					TOTAL INVESTMENT, MIL. $	
			NAPHTHA HCT	DIST. HDR	ARO HDA	H_2 PLANT	MOBIL	NAPHTHA HDT	DIST. HDR	ARD HDA	H_2 PLANT	MOBIL	EST. INVEST.	A. D. LITTLE INVEST
I	9	20.8	0	3.3	3.3	0.0	0.9	0	10.2	19.0	0	12.4	41.6	56.3
II	5	17.9	0	3.8	3.8	0.0	1.0	0	11.2	20.8	0	13.3	45.3	50.1
III & IV	8	123.7	0	25.4	49.5	0.0	0.0	0	42.5	110.3	0	0.0	152.8	148.8
V	4	71.6	0	4.4	34.5	0.0	0.0	0	12.4	87.2	0	0.0	99.6	74.7
VI	4	57.7	3.5	14.6	14.6	0.0	0.0	6.0	28.8	49.9	0	0.0	84.7	80.2
TOTAL	30	291.7	3.5	51.5	105.7	0.0	1.9	6.1	105.1	287.2	0	25.7	424.0	410.2

B. A. D. LITTLE RESULTS ADJUSTED FOR EXISTANCE OF MULTIPLE REFINERIES IN EACH GROUP

REFINERY GROUP	NO. REFINERIES	DIESEL, 000 B/D	PROCESS ADDITIONS, 000 B/D					ESTIMATED PROCESS INVEST., MIL. $**					TOTAL INVESTMENT, MIL. $	
			NAPHTHA HCT	DIST. HDR	ARO HDA	H_2 PLANT	MOBIL	NAPHTHA HDT	DIST. HDR	ARD HDA	H_2 PLANT	MOBIL	EST. INVEST.	A. D. LITTLE INVEST
I	9	20.8	0	3.3	3.3	0.0	0.9	0	19.7	41.0	0	24.0	84.7	56.3
II	5	17.9	0	3.8	3.8	0.0	1.0	0	18.2	36.5	0	21.6	76.3	50.1
III & IV	8	123.7	0	25.4	49.5	0.0	0.0	0	79.3	228.0	0	0	307.3	148.8
V	4	71.6	0	4.4	34.5	0.0	0.0	0	18.8	141.5	0	0	160.3	74.7
VI	4	57.7	3.5	14.6	14.6	0.0	0.0	9.2	43.6	80.9	0	0	133.7	80.2
TOTAL	30	291.7	3.5	51.5	105.7	0.0	1.9	9.2	179.6	527.9	0	45.6	762.3	410.2

*ASSUMING CAPACITY OF PROCESSING UNITS FOR EACH REFINERY GROUP SAME AS THAT OF ENTIRE GROUP (I.E., ONLY ONE NEW UNIT CONSTRUCTED IN EACH GROUP INSTEAD OF ONE/REFINERY).

**ASSUMING 70% HDA AND HDR CAPACITY TREATS VIRGIN GAS OIL, 25% LT. CAT. CYCLE OIL AND 5% COKER GAS OIL FOR ALL GROUPS EXCEPT I AND II WHICH ARE 100% VIRGIN GAS OIL AND THAT EACH REFINERY INSTALLS FACILITIES.

TABLE II

HYDROGEN CONSUMPTION ESTIMATES FOR 20% AROMATICS/0.14% SULFUR 1991 CASE

REFINERY GROUP	NO. REFINERIES	PROCESS ADDITIONS, 000 B/DAY		HYDROGEN REQUIREMENTS, MIL SCF/DAY*		
		DIST. HDR	ARO HDA	DIST. HDR	ARO HDA	TOTAL
I	9	3.3	3.3	1.0	3.3	4.3
II	5	3.8	3.8	1.1	3.8	4.9
III & IV	8	25.4	49.5	12.0	63.1	75.1
V	4	4.4	34.5	2.1	44.0	46.1
VI	4	14.6	14.6	6.9	18.6	25.5
TOTAL	30	51.5	105.7	23.1	132.8	155.9

ESTIMATED NET NEW HYDROGEN GENERATION CAPACITY = 155.9 (.70) = 109.1 MILLION SCF/DAY.

NOTE: THE 109 MILLION SCF/DAY NUMBER CORRESPONDS TO THE VALUE ESTIMATED BY CALIFORNIA REFINERIES NEEDED TO MEET A 20% AROMATICS/0.05% SULFUL DIESEL SPECIFICATION BASIS THE 1986 NPRA DIESEL SURVEY. THIS COMPARES TO AN A. D. LITTLE STUDY TOTAL OF ZERO.

*USED HYDROGEN CONSUMPTION NUMBERS FOR PROCESSINGS UNITS SHOWN IN A. D. LITTLE STUDY.

TABLE III

HYDROGEN CONSUMPTION ESTIMATES FOR 10% AROMATICS/0.05% SULFUR 1991 CASE

REFINERY GROUP	PROCESS ADDITIONS, 000 B/DAY			HYDROGEN REQUIREMENTS, MIL. SCF/DAY*			
	DIST. HDR	ARO HDA	MOBIL MOGD	DIST. HDR	ARO HDA	MOBIL MOGD**	TOTAL
I	9.4	8.9	11.4	2.7	9.0	2.9	14.6
II	10.6	10.2	13.1	3.0	10.3	3.3	16.6
III & IV	59.3	108.2	10.5	28.0	137.9	2.6	168.5
V	37.7	54.2	12.1	17.8	69.1	3.0	89.9
VI	36.5	36.1	8.0	17.2	46.0	2.0	65.2
TOTAL	153.5	217.6	55.1	68.7	272.3	13.8	354.8

ESTIMATED NET NEW HYDROGEN GENERATION CAPACITY = 0.7 (155.9) + (354.8 - 155.9) = 308 MILLION SCF/DAY. THIS COMPARES TO AN A. D. LITTLE STUDY TOTAL OF ONLY 105 MILLION SCF/DAY.

*USED HYDROGEN CONSUMPTION NUMBERS FOR PROCESSING UNITS SHOWN IN A. D. LITTLE STUDY.

**USED 252 SCF/BBL TOTAL FEED OR 450 SCF/BBL OF DISTILLATE FEED BASIS ADL STUDY.

TABLE IV

ADJUSTED INVESTMENT COST ESTIMATE FOR ADL 20% AROMATICS/0.14% SULFUR DIESEL CASE

REFINERY GROUP	NO. REFINERIES	PROCESS ADDITIONS, 000 B/DAY					ESTIMATED PROCESS INVESTMENT, MILLIONS $					
		NAPHTHA HDT	DIST. HDR	ARO HDA	H_2 PLANT*	MOBIL	NAPHTHA HDT	DIST. HDR	ARO HDA	H_2 PLANT**	MOBIL	TOTAL
I	9	0	3.3	3.3	3.0	0.9	0	19.7	41.0	14.5	24.0	99.2
II	5	0	3.8	3.8	3.4	1.0	0	18.2	36.5	12.8	21.6	89.1
III & IV	8	0	25.4	49.5	52.6	0.0	0	79.3	228.0	89.3	0	396.6
V	4	0	4.4	34.5	32.3	0.0	0	18.8	141.5	51.0	0	211.3
VI	4	3.5	14.6	14.6	17.8	0.0	9.2	43.6	80.9	34.6	0	168.3
TOTAL	30	3.5	51.5	105.7	109.1*	1.9	9.2	179.6	527.9	202.2	45.6	964.5

*CAPACITY IN MILLION SCF/DAY USING 70% OF TOTAL ADDITIONAL HYDROGEN REQUIREMENTS FURNISHED BY NEW GENERATING CAPACITY.

**HYDROGEN PLANT INVESTMENTS BASED ON RECENT ESTIMATE FOR STEAM/METHANE REFORMER. THIS 20.0 MILLION SCF/DAY UNIT WAS ESTIMATED TO HAVE A COST OF 23.0 MILLION DOLLARS INCLUDING OFFSITES. A SCALE FACTOR OF 0.65 WAS USED TO ESTIMATE THE COST OF OTHER CAPACITY UNITS.

TABLE V

ADJUSTED INVESTMENT COST ESTIMATE FOR ADL 10% AROMATICS/0.05% SULFUR DIESEL CASE

REFINERY GROUP	NO. REFINERIES	PROCESS ADDITIONS, 000 B/DAY					ESTIMATED PROCESS INVESTMENT, MILLIONS $					
		NAPHTHA HDT	DIST. HDR	ARC HDA	H_2 PLANT*	MOBIL	NAPHTHA HDT	DIST. HDR	ARD HDA	H_2 PLANT**	MOBIL	TOTAL
I	9	0	9.4	8.9	13.3	11.4	0	41.0	77.9	38.1	124.7	281.7
II	5	0	10.6	10.2	15.1	13.1	0	37.3	69.2	33.7	114.4	254.6
III & IV	8	0	59.3	108.2	146.0	10.5	0	143.5	378.9	173.4	114.2	810.0
V	4	4.3	37.7	54.2	76.1	12.1	10.6	84.9	189.7	89.1	101.7	476.0
VI	4	4.2	36.5	36.1	57.6	8.0	10.5	82.9	145.7	79.3	77.8	391.2
TOTAL	30	8.5	153.5	217.6	308.1	55.1	21.1	389.6	861.5	408.6	532.8	2213.5

*CAPACITY IN MILLIONS SCF/DAY USING 70% OF TOTAL ADDITIONAL HYDROGEN REQUIREMENTS AS NEW CAPACITY FOR FIRST 156 MILLION SCF/DAY AND 100% FOR BALANCE.

**HYDROGEN PLANT INVESTMENTS BASED ON RECENT ESTIMATE FOR STEAM/METHANE REFORMER. THIS 20.00 MILLION SCF/DAY UNIT WAS ESTIMATED TO HAVE A COST OF 23.0 MILLION DOLLARS INCLUDING OFFSITES. A SCALE FACTOR OF 0.65 WAS USED TO ESTIMATE THE COST OF OTHER CAPACITY UNITS.

TABLE VI

CALIFORNIA OPERATING COST COMPARISON

A. D. LITTLE STUDY

CASE	OPERATING COST (000 %/DAY)	CAPITAL COST* (000 $/DAY)	OP. COST AS % CAPITAL COST
.05% SULFUR	82.6	189.8	43.5
20% ARO	88.9	293.0	30.3
15% ARO	207.2	617.2	33.6
10% ARO	474.6	1022.2	46.4

1986 NPRA DIESEL STUDY

CASE	OPERATING COST (000 %/DAY)	CAPITAL COST* (000 $/DAY	OP. COST AS % CAPITAL COST	RATIO ADL/NPRA OP. COST AS % CAPITAL COST
.05% SULFUR	163.7	248.6	65.8	0.66
20% ARO	337.0	653.5	51.6	0.59

*(INVESTMENT X 0.25)/0.350

TABLE VII

COMBINED EFFECTS OF ADJUSTING FOR APPARENT UNDERESTIMATES BY A. D. LITTLE

	NET FEED, 000 $/DAY	OP. COST, 000 $/DAY	CAPITAL COST 000 $/DAY	TOTAL COST 000 $/DAY	TOTAL COST ¢/GAL*	INVESTMENT, MILLIONS $
20% AROMATICS/0.14% SULFUR CASE						
ADL RESULTS AS PRESENTED	84.8	88.9	293.0	466.6	3.8	410.2
(A) ADJUSTED FOR SIZE AND HYDROGEN GEN.	84.8	88.9	688.9	862.6	7.0	964.5
(B) ADJUSTED FOR (A) AND ESCALATION**	84.8	88.9	1033.4	1207.1	9.9	1446.8
(C) ADJUSTED FOR (A), (B) AND OP. COST***	84.8	310.0	1033.4	1428.2	11.7	1446.8
10% AROMATICS/0.05% SULFUR CASE						
ADL RESULTS AS PRESENTED	1885.4	474.6	1022.2	3382.2	27.6	1431.1
(A) ADJUSTED FOR SIZE AND HYDROGEN GEN.	1885.4	474.6	1581.1	3941.1	32.2	2213.5
(B) ADJUSTED FOR (A) AND ESCALATION**	1885.4	474.6	2371.6	4731.6	38.6	3320.3
(C) ADJUSTED FOR (A), (B) AND OP. COST***	1885.4	711.5	2371.6	4968.5	40.6	3320.3

*BASIS TOTAL DIESEL OF 291,700 BARRELS/DAY FROM ADL STUDY. IF BASED ON HIGHWAY DIESEL ONLY THESE VALUES WOULD DOUBLE SINCE HIGHWAY DIESEL IS 50% OF TOTAL DIESEL BASIS ADL STUDY.

**INVESTMENT ESCALATOR OF 1.5 USED WHICH IS MIDWAY BETWEEN PROBABLE RANGE OF 1.3 TO 1.7.

***OPERATING COST ASSUMED TO EQUAL 30% OF CAPITAL COST WHICH SHOULD BE CONSERVATIVE BASIS TABLE VI.

ATTACHMENT A

REQUIREMENTS FOR PRODUCING LOW SULFUR/LOW AROMATICS DIESEL

A. **Source:**

U.S. refiner's estimate for a specific refinery basis limited pilot unit studies to define hydroprocessing requirements and cost estimate for all equipment needed.

B. **Hydroprocessing Unit:**

1. Feedstock (Blend kerosine, virgin diesel, hydrotreater diesel, light coker gas oil and FCCU light cycle gas oil).

	Feed Quality	C_6+ Quality*
Gravity, °API	34	40
Sulfur, Wt%	0.5	<0.01
Aromatics, Wt%	37.0	20.0
Olefin, Vol.%	1.0	NIL

*Yield of C_6^+ product essentially 100% of feed.

2. Unit Configuration:

Capacity:	19,000 BPD
Liquid Hourly Space Velocity:	0.8 $V_0/HR/V_C$
Reactor Pressure:	1650 PSIG
Chemical H_2 Consumption:	880 SCF/BBL Charge
Total H_2 Consumption:	970 SCF/BBL Charge
Feed Gas H_2 Recycle Rate:	5000 SCF/BBL Charge
Reactor Configuration:	Multiple catalyst beds in each reactor with intermediate quench hydrogen to maintain desired maximum delta temperature across each bed. Total of two reactors.
Catalyst:	High aromatics saturation (not Noble metal)

C. **Investment Requirements:**

Equipment	Investment, Million $	Comments
19,000 BPD Hydro-dearomatization Unit	59.5	Includes Unit Offsites
20 Million SCF/D H_2 Generator (Steam/Methane Reformer)	23.0	Includes Unit Offsites
120 LT Tail Gas Treating Unit and 390 GPM Sour Water Stripper	12.8	Includes Unit Offsites
Total Investment	95.3	

D. **Total Cost to Product Low Sulfur/Low Aromatics Diesel**

Capital:	$95.3 Million
Operating:	$26,200/Day
Cost in Cents/Gal. of Diesel:	
Capital:	8.1*
Operating:	3.3
Total:	11.4

*Calculated by dividing capital cost by 4 years or on same basis as 1986 NPRA Diesel Survey.

E. **Comparison to NPRA Cost:**

NPRA Survey estimate for refinery in same crude capacity range (i.e., 30,001 - 100,000 BPD) shows total cost of 7.21 cents/gal. diesel which is only 63% of the cost estimate show above. On this basis, the NPRA costs appear understated. Discussions with a number of refiners confirms that they underestimated cost for meeting 20% aromatics due to a lack of knowledge of processing requirements since diesel dearomatization technology has not been developed.

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EMA/API Presentation

RECOMMENDED FEDERAL ON-HIGHWAY DIESEL FUEL SPECIFICATIONS TO ASSIST ENGINE MANUFACTURERS IN MEETING THE 1991 AND 1994 PARTICULATE STANDARDS

PRESENTED TO EPA
JULY 19, 1988

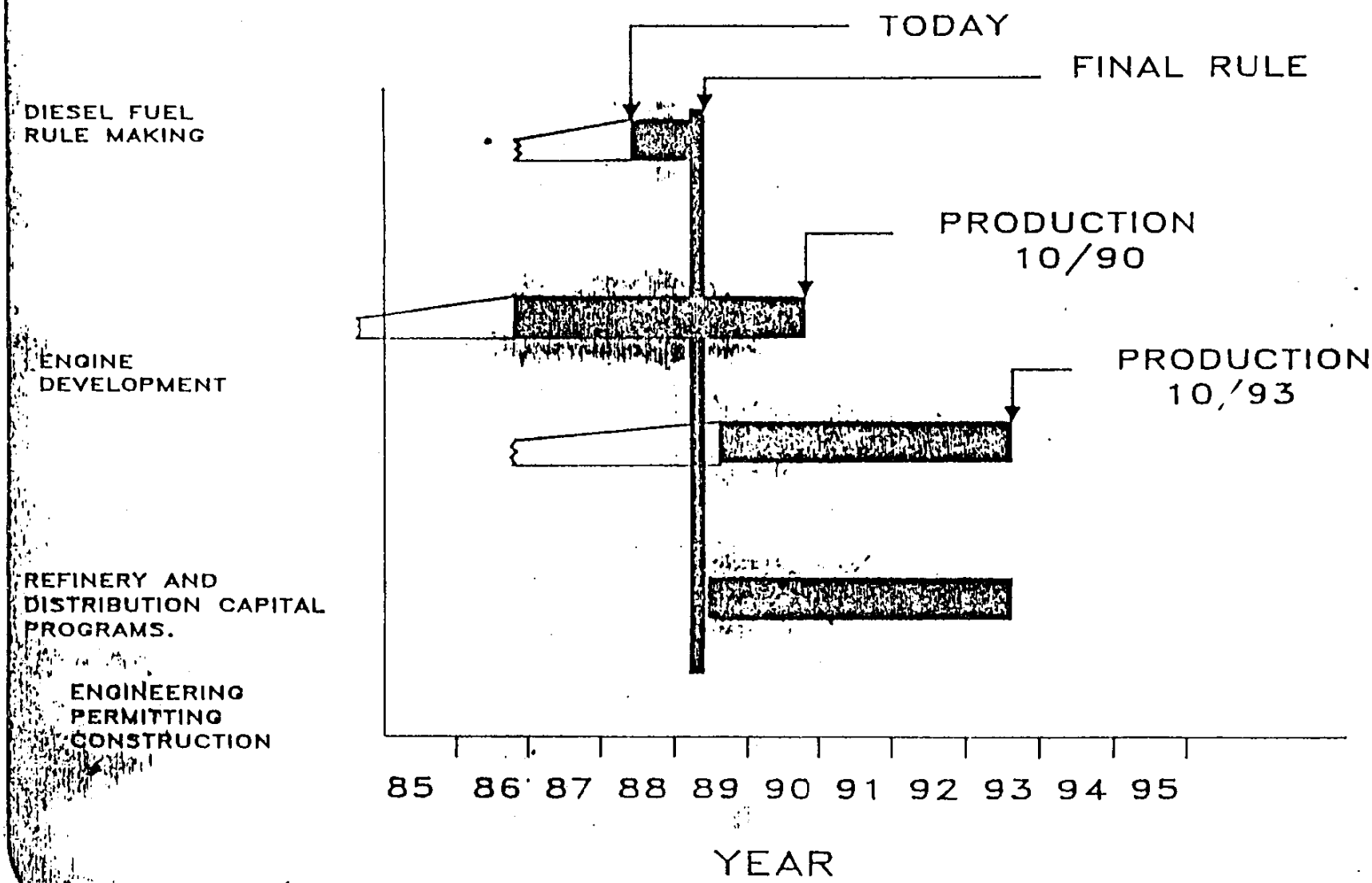
SUBMITTED BY

AMERICAN PETROLEUM INSTITUTE
NATIONAL PETROLEUM REFINERS ASSOCIATION
ENGINE MANUFACTURERS ASSOCIATION
NATIONAL COUNCIL OF FARMER COOPERATIVES

AGENDA

- INTRODUCTION
- MAJOR DISCUSSION ISSUES
  - DIESEL ENGINE TECHNOLOGY
  - PETROLEUM REFINING
  - PROPOSAL
- SUMMARY

TIMETABLE


TODAY
FINAL RULE
DIESEL FUEL RULE MAKING
PRODUCTION 10/90
ENGINE DEVELOPMENT
PRODUCTION 10/93
REFINERY AND DISTRIBUTION CAPITAL PROGRAMS.
ENGINEERING
PERMITTING
CONSTRUCTION
85 86 87 88 89 90 91 92 93 94 95
YEAR

PROPOSAL

- EFFECTIVE OCTOBER 1, 1993 FOR ON-HIGHWAY DIESEL FUEL
  - MAXIMUM .05% SULFUR CONTENT
  - MINIMUM 40 CETANE INDEX
- CERTIFY 1991-93 ENGINES USING OCTOBER 1, 1993 DIESEL FUEL
- SPECIFICATIONS APPLY UNIFORMLY TO ALL
- NO ADDITIONAL SPECIFICATIONS NECESSARY
- NO REQUIREMENT TO PRODUCE OR MARKET ON-HIGHWAY DIESEL FUEL
- FOCUS OF ENFORCEMENT ON THE MISFUELER -- AUDITING, DYEING, AND SPOT SURVEILLANCE
- SULFUR CONTENT AND CETANE INDEX CERTIFICATION BY IMPORTERS AND DOMESTIC SUPPLIERS OF ALL MIDDLE DISTILLATE FUEL
- BANKING AND TRADING IS NOT NECESSARY OR COST EFFECTIVE

"6"

DESIGN TARGETS

ACCOUNT FOR:

1. DETERIORATION
2. MANUFACTURING VARIABILITY
3. TEST VARIABILITY

MODEL YEAR	PARTICULATE STANDARD G/BHP-HR	-	DESIGN TARGET G/BHP-HR	=	COMPLIANCE MARGIN G/BHP-HR
1988	0.60		0.45		0.15
1991	0.25		0.16		0.09
1994 (1991 BUS)	0.10		0.06		0.04

EMISSION CONTROL TECHNOLOGY - 1991

IN-CYLINDER CONTROL

- FUEL SYSTEM
- ELECTRONIC ENGINE CONTROL SYSTEM
- COMBUSTION SYSTEM
- AIR HANDLING/COOLING SYSTEM
- MECHANICAL STRUCTURE/OIL CONSUMPTION

EMISSION CONTROL TECHNOLOGY - 1994

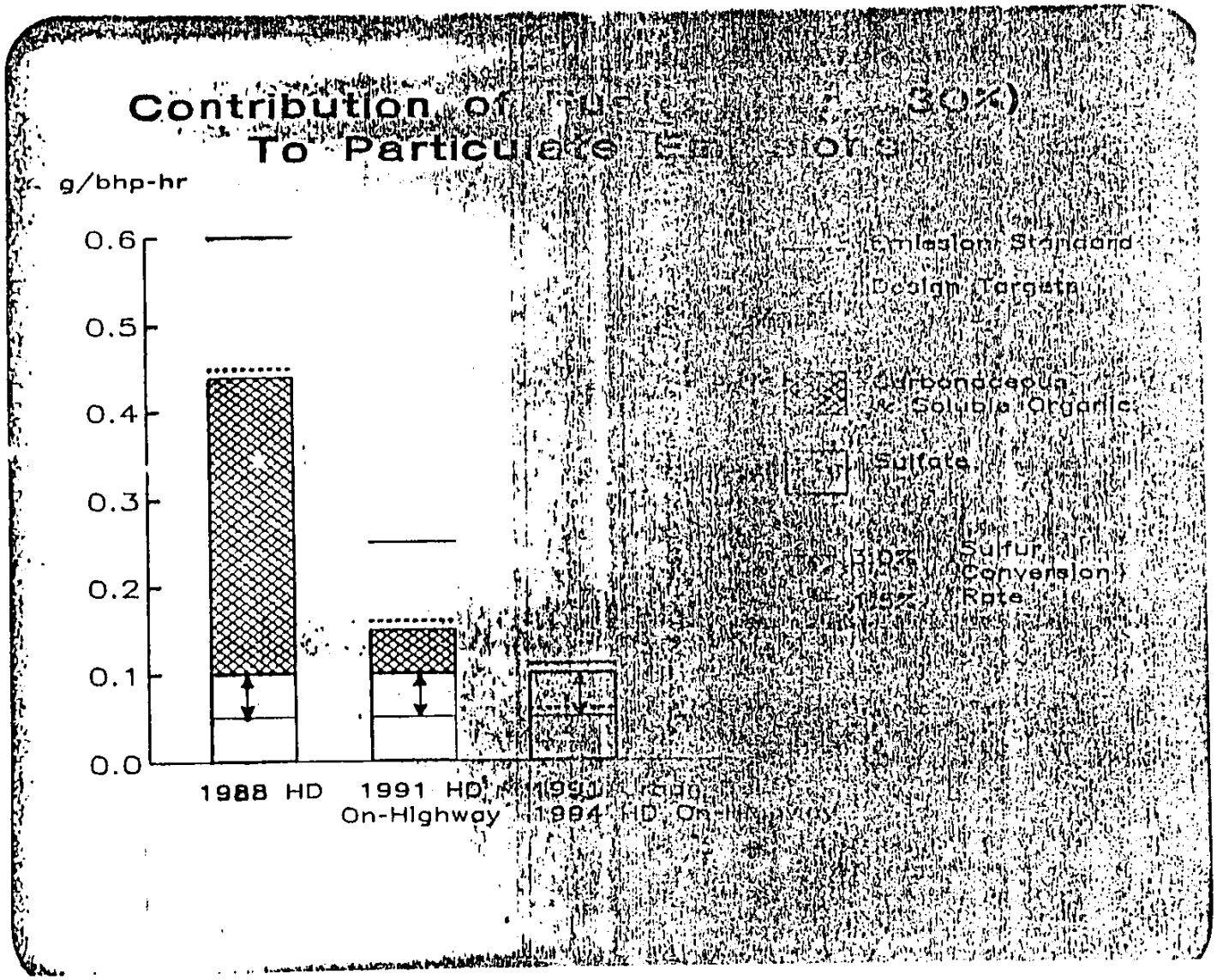
EXHAUST AFTERTREATMENT

- TRAPS
  - CATALYTIC
  - NON-CATALYTIC
  - "HEAVY-DUTY" SOLUTION
- OXIDIZERS
  - CATALYTIC
  - MAY BE REQUIRED WITH NON-CATALYTIC TRAP
  - "LIGHT/MEDIUM" DUTY SOLUTION

EFFECT OF SULFUR CONTENT ON PARTICULATE EMISSIONS

- CONSISTENT ENGINE CONVERSION RATES OF 1.5-3.0% (0.05 - 0.10 G/BHP-HR WITH 0.30%S)
- SULFATE FRACTION NOT AFFECTED BY ENGINE DESIGN

MODEL YEAR	PARTICULATE DESIGN TARGET	SULFUR-DERIVED PARTICULATE FRACTION (1.5-3.0%)
1991	0.16	31 - 63%
1994	0.06	83 - 167%


Contribution of Fuel (30%)
To Particulate Emissions
g/bhp-hr
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Emission Standard
Design Targets
Carbonaceous
& Soluble Organic
Sulfate
30% Sulfur
Conversion
Rate
1988 HD
1991 HD
On-Highway
1994 HD

PETROLEUM REFINING AND MARKETING

2 DISTILLATE DEMAND

40 %	33 %	27 %
DOE "ON-HIGHWAY" DIESEL	OTHER NO. 2 DIESEL	NO. 2 DISTILLATE FUEL OIL
• ~30% THROUGH TRUCK STOPS AND STATIONS • ~70% CENTRALLY FUELED FLEETS	• FARM • OFF-HIGHWAY (CONSTRUCTION) • INDUSTRIAL • COMMERCIAL • RAILROAD • VESSEL BUNKER • MILITARY • OIL COMPANY	• RESIDENTIAL • COMMERCIAL • INDUSTRIAL • ELECTRIC UTILITY • ALL OTHER

- "ON-HIGHWAY" DIESEL REPRESENTS ~7% OF TOTAL U.S. REFINED PRODUCTS; BY CONTRAST, GASOLINE REPRESENTS ~47%.

PROPOSAL

- EFFECTIVE OCTOBER 1, 1993 FOR ON-HIGHWAY DIESEL FUEL
  - MAXIMUM .05% SULFUR CONTENT
  - MINIMUM 40 CETANE INDEX
- CERTIFY 1991-93 ENGINES USING OCTOBER 1, 1993 DIESEL FUEL
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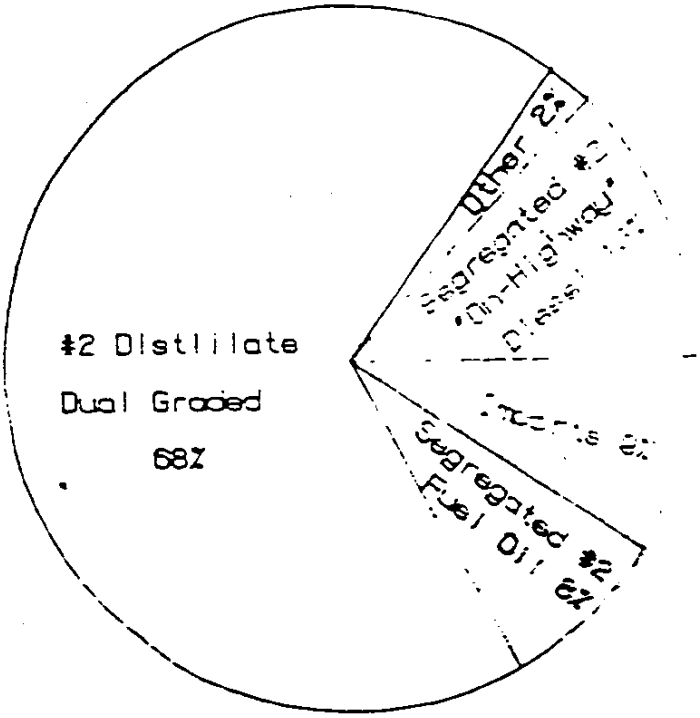
- FOCUS OF ENFORCEMENT ON THE MISFUELER -- AUDITING, DYEING, AND SPOT SURVEILLANCE
- SULFUR CONTENT AND CETANE INDEX CERTIFICATION BY IMPORTERS AND DOMESTIC SUPPLIERS OF ALL MIDDLE DISTILLATE FUEL
- BANKING AND TRADING IS NOT NECESSARY OR COST EFFECTIVE

- <u>DESULFURIZATION</u>
  - TECHNOLOGY
  - COSTS
  - LEAD TIME
- <u>AROMATICS</u>
  - CETANE INDEX

FUEL EFFECTS ON PARTICULATE EMISSIONS

- SULFUR
- AROMATICS

#2 DISTILLATE SUPPLY



Western Oil and Gas Association
505 No. Brand Blvd., Suite 1400 • Glendale, California 91203
(818) 545-4105

Dean 8/16/88 (173)

August 3, 1988

Mr. James Boyd
California Air Resources Board
P. O. Box 2815
Sacramento, California 95812

Subject: CARB June 27, 1988 Workshop -- Draft Deisel Regulations for Sulfur and Aromatic Content

Dear Mr. Boyd:

The Western Oil and Gas Association (WOGA) appreciated the opportunity to discuss with your staff some of our preliminary concerns with the draft sulfur and aromatic diesel fuel regulations that were passed out at the subject workshop.

Although we appreciate your staff's efforts to provide us such information as quickly as they could, we are still very concerned about the impending October Board hearing on diesel aromatic regulations given the unavailability of important documents and information so late in the regulatory process. For the July 27 and August 5 diesel workshops, workshop notices were sent out with less than two weeks' notice. Information to be discussed at the workshop has not been available until the day of the workshop, and then only summaries or portions of reports were available. The only workshop on vehicular emissions was so poorly noticed that only one oil company was able to attend at the last minute and most oil companies learned of the workshop afterward.

There is still no acceptable analytical method to measure aromatics in diesel to assess the true impact of a rule on a specific refiner. With only a few days left prior to the required notice of an October hearing, we have yet to see the ARB's cost-effectiveness estimates for reducing aromatics in diesel. With these deficiencies in mind, we strongly recommend that you defer taking any action that reduces aromatic content in diesel until these issues are more fully discussed.

Our detailed comments on the draft regulations are attached. Our major concerns and recommended improvements are as follows:

1. We have yet to see any persuasive evidence that the reduction of aromatics in diesel fuel is a cost-effective method to reduce emissions in the United States or California. The American Petroleum Institute (API) and the Engine Manufacturer's Association (EMA) have agreed to a national position that calls for availability of diesel fuel by October 1, 1993 with 0.05 wt. per cent sulfur, and a minimum Cetane Index of 40 to cap, but no reduction in the aromatic content. If incremental diesel emission reductions are needed in California or sections of California, a more thorough comparison of fuel controls versus vehicular controls should be made, along with consideration of an aggressive Inspection and Maintenance Program.

2. The ability of California refiners to obtain the necessary permits to construct and operate the new equipment necessary to modify diesel fuel is a major concern. Given current and proposed air quality control districts' regulations on new and modified stationary sources, many diesel producers would be hard pressed to continue the production of diesel to their current customers.

3. Critical issues concerning administration of aromatics regulation remain unresolved, e.g., the method of averaging, the length of the averaging period, the prenotification and variance requirements and, most critically, how aromatics can even be measured.

Thank you for your consideration of our concerns and recommendations. If you have any questions about our comments, please do not hesitate to contact me or Mr. Michael Wang, Manager of our Environmental Affairs Division, (818) 545-4105.

Very truly yours,

Michael Wang for

Douglas Henderson
Executive Director

DH: va
Attachment

ccs: Mr. Peter Venturini, ARB
Mr. Dean Simeroff, ARB
Ms. Jananne Sharpless, ARB Board Member
Mr. George Baily, ARB Board Member
Dr. Eugene Boston, ARB Board Member
Mrs. Roberta Hughan, ARB Board Member
Mrs. Betty Ichikawa, ARB Board Member
Mr. John Cefala, ARB Board Member
Mr. John LaGarias, ARB Board Member
Mrs. Harriet Wieder, ARB Board Member
Dr. Andrew Wortman, ARB Board Member

COMMENTS OF THE WESTERN OIL AND GAS ASSOCIATION
ON CARB'S DRAFT DIESEL SULFUR/AROMATIC REGULATIONS

(Attachment of Letter Dated August 3, 1988)

1. A definition is needed for producer. We recommend that a producer be defined as a refiner, blender, or importer of diesel fuel. Refiner and importer should be defined according to 40 CFR, Section 80.2. A definition of blender will be supplied at a later date.

2. In the colder months and at higher elevations, diesel fuel must be cut with jet fuel to lower the cloud point to ensure proper vehicular operation. Since this is nominally a small volume of diesel which is only produced for a short period of time and is not used in major urban areas, we request that from October through March such diesel be exempted from meeting (a) (1) provided the diesel fuel basestock complies with the proposed requirements.

3. Subsection (a) (1) contains a blank for the date by which producers would need to be producing fuels in compliance with these two draft regulations. We recommend this date be October 1, 1993. This time period is reasonable due to the extent of modifications required for most major facilities to comply with both regulations, and the likelihood that construction permits will be very difficult to obtain.

4. Section a(2) requires bulk-purchasers to comply with the sulfur and aromatic limits. To make a(2) consistent with the provisions of a(1) and a(5), it is important, especially for the aromatics draft, that a(2) be revised from:

> "...has a/an sulfur/aromatic hydrocarbon content greater than...."
>
> to
>
> "...does not comply with the standards set forth in Section (a) (1), and (a) (5)."

5. Section (a) (5) (A) requires that a producer or importer notify the executive officer 24 hours before beginning physical transfer of a batch of diesel fuel that exceeds the (a) (1) aromatic limit. This time period is apparently to provide the ARB enough time to independently obtain a sample of fuel prior to the fuel's transfer.

Holding a tankfull of diesel fuel for 24 hours after it has been finalized would create significant product movement problems within our refineries, pipeline systems and terminals. It may force some companies to build additional unnecessary tankage if required to comply with this provision.

Shipment schedules with common carrier product pipelines are established two weeks in advance. Roughly three to five pipeline shipment tenders per day can be scheduled from a complex refinery. Current refinery and terminal inventory levels allow for a refinery tank holding time of from nil up to a week, with an average time of about three days. Thus a 24-hour delay would represent a significant problem in refinery and terminal inventory planning, pipeline scheduling, and ultimately, in product availability at terminals for use by consumers.

WOGA does not believe that providing the required prenotice is necessary provided the producer retains lab samples properly, maintains good lab records, and complies with a requirement to notify the ARB of such batches prior to transferring them. We understand from discussion with representatives from the ARB's Compliance Division that the compliance record for the vast majority of fuel sold in California has been very good. There is no reason to suspect that this excellent record will change due to our recommendations.

We would also request that you consider one other option; namely, to draft regulations that would direct the ARB to enter into a contract with the Air Quality Management Districts or some other third party to quickly obtain fuel samples from producers. Such a contract would require the sample to be drawn within some relatively short period of time after notification, i.e., 1-3 hours.

Regardless of the approach chosen, the producer should be quickly advised as to whether or not a sample is to be taken by the ARB or some third party. If no sample is to be taken, the producer should be allowed to release the fuel, and not unnecessarily restrict his operations. This would be particularly important if an extended prenotice period were adopted.

6. Section (a) (5) (A) also requires that if actual values are later determined to be different than originally reported, the producer needs to report the revised values within 24 hours after the start of the physical transfer.

If an error is made due to human, or mechanical causes, there is no reason to suspect that all such errors will, or could be detected within 24 hours of the physical transfer of the fuel. Such errors should be reported to the ARB within 24 hours of becoming known to the producer.

7. Section (a) (5) (B) sets the averaging period in which any batches of fuel above the limit is to be offset by an equal volume of fuel below the limit.

If an aromatic limit is specified, WOGA recommends the averaging period be no shorter than 365 days. With the current understanding of the potential benefits from diesel aromatic controls, it is unreasonable to require a shorter averaging period.

8. Section (a) (5) (B) also requires that the ARB be notified 48 hours prior to the transfer of batches that are to be used to offset high batches. It is unclear why this prenotice is longer than the one in (a) (5) (A). This second prenotice period should be the same length as the one discussed in item 5 of our comments above for Section (a) (5)(A).

WOGA recommends the same revisions to (a) (5) (B) as for (a) (5) (A).

9. Section (a) (6)(b) requires that ASTM Test Method D 1319-84, or an equivalent method, be used to measure diesel aromatic content. In earlier discussions between the ARB's and WOGA's analytical experts, it was agreed that the cited method is unacceptable for compliance purposes for the regulation of aromatics in diesel.

The analytical method chosen by both our analytical experts which seems to show the greatest promise is High Performance Liquid Chromatography (HPLC). Unfortunately, HPLC has yet to go through a well run round robin test to fully evaluate its credibility, repeatability, and reproducibility. There are also very few HPLC's in operation within California/West Coast refineries. The issue of HPLC detector availability is also of concern. Making an accurate evaluation of the impact of any aromatic control measure will be dependent upon knowing the aromatic content of diesel fuel using a method which has acceptable repeatability and reproducibility.

We therefore recommend that you defer adoption of any aromatic controls that require analysis of aromatic content until this, and other important issues relative to aromatics, are resolved.

10. Section (f) (1) states that only "extraordinary" reasons beyond the person's control would justify a variance. We believe it is reasonable to allow a person to request a variance for any reason that is beyond the control of the operator. The draft regulation provides more than adequate criteria to reject unwarranted variance requests.

11. From previous discussions, the ARB had agreed to check into whether or not other State laws would apply to the draft diesel regulations and thereby prevent individuals from obtaining variances that had not shown a good faith effort to comply with the initial compliance date of a rule. Our primary concern is that individuals would request, and possibly be granted, an extension for initial compliance without having put forth a good faith effort to comply.

The potential emergence of such a situation could be avoided by adding the following requirement:

Each California producer shall submit to the executive officer within one year after adoption of this regulation a plan setting forth the steps which are scheduled to come into compliance. At annual intervals thereafter, each producer shall report to the executive officer their progress toward attaining compliance by October 1, 1993.

A variance under subsection (f) (1) shall only be available to producers which have submitted compliance plans and annual progress reports.

12. Section (f) (8) provides that a variance due to a breakdown, repair, or malfunction shall not exceed six months, while the preceding section (f) (7) provides up to a three-year variance during construction of major additional equipment. There are certainly examples within a refinery where a breakdown, repair or malfunction would take more than 6 months to fix, and not include the construction of major additional equipment. We would recommend that Sections (f) (8) be deleted, and (f) (7) be revised to simply read:

> "No variance from the requirements set forth in subsection (a) (1) shall have a duration of more than three years."

The executive officer has the authority to set the variance length commensurate with the situation. No further definition is required.

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Allied Signal

June 21, 1988

Mr. John Courtis
California Air Resources Board - Fuels Section
1102 Q Street
Sacramento, California
95812

Dear John:

Per our recent phone conversations, I would like to confirm in writing a number of the points that we discussed as well as transmit some descriptive information relative to UOP's AH Unibon Process.

I would again like to qualify the information that we passed along to ADLittle - our commercial experience base for the AH Unibon process is limited to straight run crude fractions with endpoints in the 575 deg. F range. Data from the Pertamina unit, discussed later, is typical of this type of operation. The aromatic content of such feedstocks seldom exceeds 35%. Typically, moderate levels of aromatics saturation are desired for such kerosine fractions, to achieve smoke point specifications. Other applications of the AH Unibon process achieve very high aromatic conversion (>95%) when processing low aromatic content kerosine extracts or naphtha fractions.

The processing of heavy straight run fractions, cracked stocks, and LCO is an extrapolation of our commercial database. Process-wise, we feel that these stocks can be successfully processed in the AH Unibon process, but that pilot plant work is required to determine:

1) First-stage process conditions to achieve the low contaminant levels required for the second stage H-8 catalyst

2) Second-stage process conditions to achieve the desired level of aromatics saturation and the resultant hydrogen consumption

3) Second-stage process design to accommodate the very high heat of reaction related to high aromatics conversion of highly aromatics feedstocks such as LCO. Such a design would likely include multiple reactors with hydrogen quench points as well as liquid product recycle to dilute the reactor feed aromatics concentration. Such a process design would result in a higher capital cost relative to a conventional AH Unibon unit, probably on the higher end of the +/- 40% cost estimate made for the LCO saturation unit.

As we discussed on the phone, we feel that the process can achieve high levels of aromatics saturation (greater than the 70-75% shown in the ADL report). Our uncertainty relates to the process conditions required and the economic implications, especially as related to the considerable hydrogen consumption.

As we discussed, a rule of thumb for relating hydrogen consumption to additional aromatics saturation beyond the 20% aromatics in the product for the ADL light cycle oil case, is to assume an additional 30 SCFB for each additional LV% aromatics converted. The 2000 SCFB quoted for the reduction from 70 to 20 LV% aromatics assumes a distribution of mono and bi-cyclic aromatics in the LCO; the additional 30 SCFB/LV% aromatics assumes only mono-cyclics remain. The hydrogen consumption is obviously dependent on the assumed LCO composition and would change significantly with a higher bi-cyclic aromatic content. These hydrogen consumption numbers reflect chemical consumption and additions for solution/mechanical losses must be considered. Pilot plant work is needed to confirm these numbers.

Enclosed please find the following information:

1) AH Unibon Process Description and process flow diagram
2) AH Unibon commercial experience list - this list is a mixture of a number of types of units including a) single stage units using conventional HDS catalyst, b) single stage units using H-8 catalyst where the feed is already desulfurized, and c) two stage units with HDS catalyst in the first stage and H-8 catalyst in the second stage.

The Pertamina unit shown at the bottom of the list is the best example of the process as it would be applied to aromatics reduction of diesel fuel. This unit processes a full range kerosine feedstock with a processing objective of 25 mm smoke point jet fuel. The resultant aromatics conversion is around 75%. Some typical data from this unit is attached following the licensed unit list.

I've also included some pilot plant data processing a 460-602 deg. F. straight run fraction labeled "Feed M". Two levels of processing severity are shown with the more severe operation producing less than 1% aromatics in the product.

Also on the commercial experience is the Kern County Refining unit in Bakersfield. This unit apparently processes a hydrotreated heavy naphtha on a blocked out basis to produce a speciality product. I am not personally aware of the current ownership or status of the refinery nor the status of this particular unit.

Please let me know if you have any questions about this information or if I can be of any further assistance.

Yours truly,

Robert F. Denny
Marketing Manager Fuels Processes
Marketing Services Department
UOP Inc.

UOP AH UNIBON TECHNOLOGY FOR AROMATIC SATURATION

Introduction

UOP's AH Unibon is a catalytic process which treats hydrocarbon feedstocks for aromatic reduction with very minor conversion to lower boiling compounds. A major application of the process is the production of high quality jet fuel from straight run kerosines.

In addition to its use in jet fuel production, the process can be utilized to improve the ignition quality of diesel oils, the burning quality of illuminating kerosines, and to yield other specialty products of low or nil aromatic content, such as naphtha solvents, aromatic-free normal paraffins for further production of single cell proteins, heavy food grade white oils or SAS intermediates.

Process Description

As typically applied to production of jet fuel, the AH Unibon unit consists of a hydrotreating section and an aromatic hydrogenation section. Should the feed be already hydrotreated, as is the case with normal paraffins from Molex units, the hydrotreating section would not be required.

In the hydrotreating section raw feed is mixed with makeup and recycle hydrogen, preheated and charged to the reactor where sulfur, nitrogen and oxygen contained in the feed are converted to hydrogen sulfide, ammonia and water. The hydrotreating catalyst employed in this reactor promotes contaminant removal at moderate operating conditions. The operation is conducted at relatively low pressure and high space velocity (minimum catalyst loading). The reactor effluent is then cooled and directed to a separator from which hydrogen rich gas is recycled to the reactor. Separator liquid is directed to a stripping column, primarily for the removal of hydrogen sulfide and dissolved light gases.

The hydrotreating section stripper effluent is sent to the aromatics hydrogenation section where it is mixed with recycle and makeup hydrogen, heated and charged to the aromatic saturation reactor. A highly active hydrogenation catalyst that selectively saturates the aromatics contained in the feed is employed here. The reaction is carried out at low pressure and intermediate space velocity with the specific conditions determined by feed characteristics and the extent of aromatic saturation necessary to meet product requirements. Reactor effluent is cooled and directed to a separator for recovery of recycle hydrogen. Separator liquid is stripped in a stripping column for removal of dissolved hydrogen and light ends which may have entered the unit with the makeup gas.

If required, operating conditions may be selected to yield a product almost entirely free of aromatics. Minor amounts of light ends are produced, essentially all of which are a result of the fracturing of the contaminant carrying organic feed compounds in the hydrotreating section. With the exception of the small consumption of hydrogen due to

removal of feed contaminants in the hydrotreating section, virtually all hydrogen is used for the saturation of aromatics.

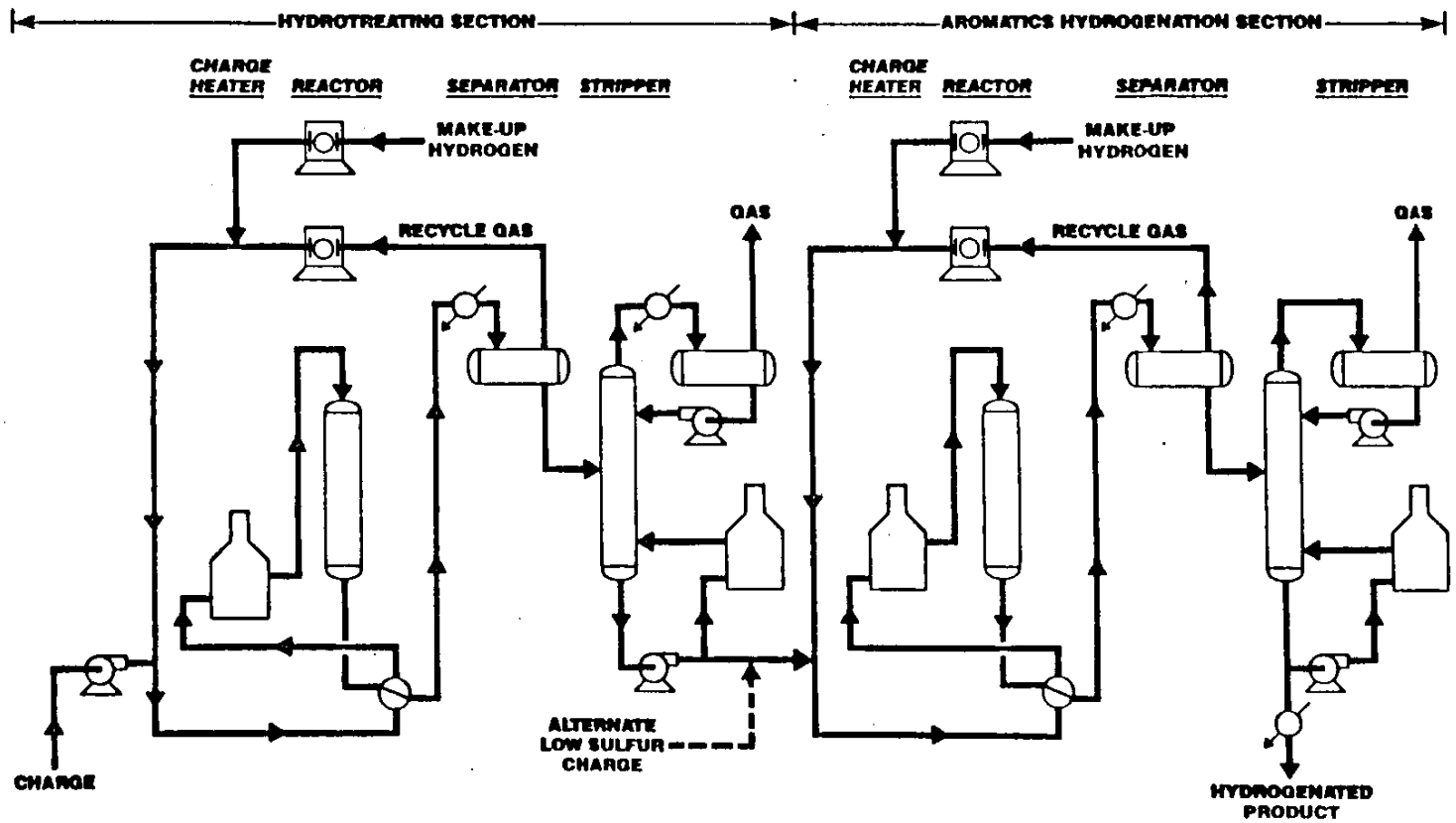
Both the hydrotreating and the hydrogenation catalysts have been thoroughly pilot plant tested and have proven successful over the years in a number of commercial installations. The catalysts are regenerable and will achieve long ultimate useful service.

Since operating severity in both sections of the unit is moderate, exotic materials of construction are not required.

Commercial Experience

UOP's commercial experience in the field of aromatic saturation spans many years on variety of petroleum fractions. Three units have been designed and commissioned for n-paraffin dearomatization. Two distillate AH Unibon units have also been brought on-stream to reduce the aromatic contents of kerosines and gas oils. Two naphtha AH Unibon units have been commissioned for solvent production. An additional two units have been designed for kerosine dearomatization for use as jet fuel.

UOP AH UNIBON PROCESS



AH UNIBON

UOP LICENSED UNITS

January, 1986

LICENSEE	LOCATION	BPSD	TYPE	START-UP
Saras Chemica	Sarroch, Italy	3,030	1 Stage	1976
Hunt Oil	U.S.A.	400	1 Stage	1979
Romchim	Romania	2,508	1 Stage	1979
Chemica Augusta	Italy	2,250	1 Stage	1982
Petrochemical Industries Corp.	Mann, Burma	3,000	1 Stage	1982
Pertamina	Cilacap, Indonesia	20,000	2 Stage	1983
Kern County	U.S.A.	1,700	1 Stage	1983

PROPERTIES OF TYPICAL PRODUCTS FROM FEED M

	FEED	PRODUCT	PRODUCT
°API	36.1	37.5	38.1
DISTILLATION, VOL-%			
IBP, °F	460	441	450
5%	469	462	459
10%	474	469	465
30%	492	490	487
50%	511	509	508
70%	532	532	529
90%	565	568	570
95%	587	584	589
EP	602	606	600
AROMATICS, UV, WT-%	(20.9 LV-%)	4.8	0.3
CETANE NO.	50.2	52.1	54.1
FREEZE POINT, °F	-50	-48	-46

UOP 610-11

UOP AH UNIBON PROCESS

PERTAMINA 2 STAGE UNIT

	Raw Feed	Product 1st Stage	Product 2nd Stage
API Gravity	36.1	37.0	40.4
ASTM IBP F	300	–	–
EP	570	–	–
Sulfur, ppm	500	<5	–
Nitrogen, ppm	10	<1	–
Aromatics, vol.%	32.4	31.0	7.0
Smoke Pt., mm	14.8	–	25.0