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A Comparison of Heavy-Duty Diesel Truck Engine Smoke Opacities at High Altitude and at Sea Level

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ABSTRACT

A study was conducted by the California Air Resources Board to investigate the effects that altitude has on in-use heavy-duty diesel truck smoke opacities. The understanding of these effects may allow for the establishment of a high altitude opacity standard for diesel trucks operating at or above altitudes of 5800 feet. During a three-week study, 170 heavy-duty diesel trucks were tested at an altitude of 5,820 feet using a test procedure consisting of rolling acceleration and snap idle tests. Eighty-four (84) of these trucks were recaptured and retested at an altitude of 125 feet. Results from a regression analysis indicates that, on average, truck smoke opacities increased by 23 opacity points when tested at altitudes near 6000 feet. Possible high altitude cutpoints and failure rates are also discussed.

INTRODUCTION

In-use heavy-duty diesel vehicles significantly impact air quality in California. The projected 1991 statewide exhaust emissions from heavy-duty diesel vehicles is 107 tons per day for hydrocarbons (HC), 543 tons per day for oxides of nitrogen (NOx), and 123 tons per day for particulate matter (PM). These heavy-duty diesel vehicles account for 30 percent of the NOx emissions and 75 percent of the PM emissions of the entire on-road vehicle fleet even though these vehicles only account for approximately 2 percent of the on-road vehicle fleet (1).

Diesel exhaust contains numerous compounds emitted in gaseous and solid (particulate) phases. The gas phase contains a variety of compounds including carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen and hydrocarbons. Numerous toxic compounds, including benzene, 1,3-butadiene and formaldehyde, have been identified in diesel exhaust and are generally determined to be constituents of the hydrocarbon portion of the exhaust stream. The particulate phase emissions consist primarily of soot, sulfates, and high molecular weight hydrocarbons (e.g. polycyclic aromatic hydrocarbons [PAHs]) which tend to absorb or condense on the soot. In general, soot accounts for approximately 50% of the total particulate mass while the sulfates and high molecular weight hydrocarbons account for approximately 20% and 30% respectively (2). Although no quantitative relationship has been demonstrated to date, it is widely held that reductions in diesel particulate and hydrocarbon emissions correspond with lower smoke opacities (3).

Diesel exhaust constituents have been identified as toxic air contaminants under the California Air Resources Board's (ARB) Toxic Air Contaminant Program as mandated by California Assembly Bill 1807 of 1983 (4). HC and NOx emissions contribute to California's inability to meet ambient ozone standards resulting in increased public health impacts, reductions in agricultural production, and other adverse environmental impacts. Additionally, excessive exhaust smoke, primarily caused by emissions control systems tampering and malmaintenance, is a target of numerous public complaints from concerned citizens.

To address this problem, the California State Legislature passed Senate Bill 1997 in 1988. Senate Bill 1997 provided for enhancements to California's existing inspection and maintenance (I/M) "SMOG CHECK" program and authorized the California Air Resources Board (ARB), in cooperation with the California Highway Patrol (CHP), to establish a Heavy-Duty Vehicle Smoke and Tampering Inspection Program (HDVIP) for California and out-of-state registered heavy-duty diesel and gasoline powered vehicles. Regulations are being finalized to implement the provisions of SB 1997 establishing the HDVIP. Pending promulgation of these regulations, which is anticipated to occur in the summer of 1991, heavy-duty diesel trucks and busses will be inspected for excessive smoke emissions and tampering of engine and emission control components. Heavy-duty gasoline trucks and busses will be inspected for emissions control systems tampering. Vehicle owners found to be in violation of the prescribed test procedures will be subject to substantial civil penalties and, in extreme situations, may have their vehicles placed out-of-service (5).

HDVIP inspection locations will include CHP Commercial Vehicle Inspection Facilities (CVIFs) and Platform Scales (PFs), random roadside locations, and public and private truck and bus fleet facilities statewide. The current cutpoint has been derived from low altitude testing. This study was done to determine the effects of high altitude on diesel truck smoke opacities.

In developing the HDVIP, ARB conducted three pilot studies in order to quantify the smoke emission levels emitted from in-use heavy-duty diesel trucks and to gain practical experience in conducting inspections (6). The most recent study, referred to as the High Altitude Recapture Program (HARP), was conducted from September 12 through October 3, 1990. During HARP, trucks were inspected for peak smoke opacity at a high altitude test site, tagged with a highly visible sticker, then recaptured and retested at the low altitude test site. The high altitude test site was located at Truckee, California at an altitude of 5820 feet and the low altitude site was located at Sacramento, California at an altitude of 125 feet above sea level.

This paper discusses the test procedures and smoke opacity data collection and analysis methodologies used during this HARP study; as well as the effects of altitude on in-use heavy-duty diesel truck engine smoke opacity. It should be noted that HARP was a one site study of a limited number of trucks and does not adequately examine all of the possible parameters influencing truck smoke opacity. Consequently, further studies may be necessary. Trucks were selected for HARP on a near random basis, in that, only heavy-duty diesel trucks with gross vehicle weight ratings (GVWR) above 6000 lbs. were selected.

EXPERIMENTAL

SMOKE OPACITY MEASUREMENT - Measurement of smoke opacity was made using an opacity meter connected to a strip chart recorder and by a visual observation. The opacity meter used was a Wager 650A end-of-line light extinction type meter, with an effective optical path length of 8.375 inches. The Wager meter consists of two parts; the control unit and the sensor head. The measurement of opacity is based on principles of the Beer-Lambert Law and is accomplished by passing the exhaust particles between the light source and sensor located in the sensor head. As exhaust particles pass the light beam, a percentage of the light is blocked resulting in a drop in light transmittance. This drop is then converted to an opacity value by the control unit. The output voltage from the meter ranges from 0 to 1.0 volt and corresponds to the opacity scale of 0 to 100 percent opacity; zero (0) being equivalent to no visible opacity and one hundred (100) being equivalent to total blackness. Resolution of the meter was to the nearest percent. The Wager meter meets industry standards as defined in Society of Automotive Engineers (SAE) specifications J1243 (7).

Visual observations of smoke opacity were made simultaneously during each of the truck inspections by an ARB certified smoke reader. Previous studies (8) have concluded that visual measurement of smoke opacity, in general, has excellent correlation with the meter readings. However, visual observations, conducted over extended periods of time, result in unacceptable variability; therefore visual observations were used primarily as a quality assurance check of the opacity meter.

TEST PROCEDURE - Trucks were selected on a near random basis, in that, trucks with a GVWR of less than 6000 lbs. and gasoline powered vehicles were not selected. Each truck tested at the high altitude site was run through two (2) rolling acceleration tests, a series of six (6) snap idle smoke tests (no-load accelerations), and an underhood inspection. For all high altitude tests, the smoke sensing equipment was rigidly affixed to each truck. The optical sensor head was mounted in a radial orientation at the termination of the exhaust stack so that the light path of the sensor intersected the exhaust plume approximately 2 inches past the exhaust stack outlet and at right angles to the central axis of the exhaust plume, in accordance with SAE specifications J1243 (9) and J255a (10). At the conclusion of each high altitude inspection, trucks were tagged with a highly visible sticker, for the purpose of recapture, and released.

Rolling Acceleration Test - A rolling acceleration test is a moving vehicle test and is an effective test for determining smoke opacity levels, because the truck is subjected to the highest engine loading (11). This test mimics the loading characteristics of the Federal Smoke Certification test cycle specified in SAE J1003 (12). Although this test is an effective test, it is impractical at locations with limited test lane space. The rolling acceleration also poses safety concerns since it is a moving vehicle test.

To conduct the test, the truck operator was instructed to place the transmission of the truck in the lowest gear (first gear, low). From a stopped idle state, the operator was then instructed to engage the clutch and start the truck rolling at an engine speed, approximately 200 RPM's above idle. From this speed, the throttle pedal was rapidly depressed to the full power position, causing the engine and truck to accelerate to the full governed speed. During the acceleration, smoke opacity was measured by a visual observation and by an opacity meter connected by a strip chart recorder. After maintaining governed speed for 4 to 5 seconds, the throttle pedal was released and the truck was brought to a stop.

Snap Idle Test - The snap idle test is a stationary vehicle test and is preferred because it is easy to perform and produces repeatable results. It accommodates locations with limited test space and is inherently safer since it is a stationary vehicle test.

To conduct this test, the wheels of the truck were chocked, the brakes were released, and the transmission was placed in neutral. From a no-load idle condition, the operator was instructed to rapidly depress the throttle pedal to the full power position, causing the engine to rapidly accelerate to the maximum governed RPM. After 3 to 4 seconds at governed speed, the throttle pedal was released, allowing the engine to return to an idle state. This procedure was repeated three or more times to precondition the engine. After preconditioning, three more snaps were performed. Peak smoke opacity was measured during each engine acceleration.

Underhood Inspection - Following smoke testing, a detailed underhood inspection was performed on each truck. Data collected included: truck specific data such as truck make, model year, axle configuration, GVWR, vehicle identification number, and license number; trip specific data such as origin, destination, fuel grade and refueling location; and engine specific data such as engine make, model and model year, horsepower, configuration, rated speed, and engine family.

FIELD STUDY

TRUCKEE WESTBOUND INSPECTION FACILITY (TRW) - The CHP's Truckee commercial vehicle inspection facility (TRW) was selected as the high altitude test site. Located at an altitude of 5,820 feet, the facility is located on westbound Interstate-80 approximately sixteen (16) miles west of the California/Nevada stateline. The facility is operated year round, twenty-four (24) hours per day, seven (7) days per week by personnel of the CHP for the purposes of commercial vehicle safety inspections and weight enforcement. The facility is a racetrack design and is equipped with four fully enclosed inspection bays. During the HARP study, trucks were tested on approximately 350 feet of the facility's return lane. Both rolling acceleration and snap idle tests were performed at TRW.

ANTELOPE WESTBOUND PLATFORM SCALE (ANW) -The recapture site was the CHP's Antelope platform scale (ANW) located in Sacramento, California on westbound Interstate-80. ANW is located approximately 100 miles west of TRW. The altitude at the ANW is approximately 125 feet above sea level. This platform scale is operated by the

CHP year round, sixteen (16) hours per day, five (5) days per week. Commercial vehicle weight enforcement is the primary objective of this facility; however, safety inspections are also conducted. Because of the limited size of the facility, only snap idle tests were performed on the recaptured trucks. Specific information pertaining to TRW and ANW are presented in Table I.

DATA COLLECTED - The data collected from the HARP study consisted of 170 inspection records of in-use heavy-duty trucks tested at TRW. Of these, 84 trucks (49%) were recaptured and retested at ANW; most on the same day and same trip. Of the 170 trucks inspected at TRW, 143 were heavy heavy-duty trucks, 23 were medium heavy-duty trucks, and 4 were light heavy-duty trucks. Engine model years ranged from 1972 through 1991 with 56 percent of the engines having model years between 1987 to 1990. The engine makes identified were 52 percent Cummins (Cumm), 32 percent Caterpillar (Cater), 8 percent Detroit Diesel Corporation (DDC), and 8 percent were other engine makes.

For the purpose of data analysis, a final opacity value was derived from the metered snap idle opacity results. To derive this value, an average was calculated for the two most consistent measured snap idle tests. The final snap idle opacity values for trucks tested at both TRW and ANW are presented in Table II. The table fields include: engine model year .MY), engine manufacturer (MFR), engine model (MODEL), horsepower rating (HP), engine displacement (DISP) in liters, engine aspiration (ASPIR) (T - turbocharged, N - naturally aspirated), average metered snap idle opacity at Antelope (ANW SM), average metered snap idle opacity at Truckee (TRW SM), and the difference in opacity between Antelope and Truckee (DIF). Entries are sorted by descending order of opacity difference.

DISCUSSION OF DATA ANALYSIS

Analysis of the data presented in Table II was performed using a least squares regression technique. A regression was done for the average of the two most consistent metered snap idle tests for TRW vs. ANW. The results of this regression are shown in Figure 1 and are based on the 80 trucks tested at both TRW and ANW. Four (4) trucks out of the 84 recaptured were omitted from the regression analysis because the data were incomplete. The results of this regression indicates a fair correlation between the high altitude snap idle test and the low altitude snap idle test as indicated by the coefficient of determination ($r^2 = 0.619$) and a correlation coefficient ($r = 0.787$). The mean snap idle opacity readings at low altitude and high altitude were 39.0 and 62.3 respectively. This corresponds to an average opacity increase of 23.3 opacity points. The resultant regression equation is as follows:

<u>Regression of Truckee metered snaps idle opacities vs. Antelope metered snaps idle opacities (n=80)</u>

$$\text{TRW SM} = 29.197 + .848(\text{ANW SM}) \quad (1)$$
$$(r^2 = 0.619)$$
$$(r = 0.787)$$

TRW SM - average of two most consistent metered snaps idle opacities at Truckee.

ANW SM - average of two most consistent metered snaps idle opacities at Antelope.

The snap idle opacity values from TRW and ANW (Table II) were plotted on a cumulative distribution chart (Figure 2). A cumulative distribution chart is useful for showing the typical range of smoke opacities observed as well as allowing the expected failure rate to be readily determined for any pass/fail cutpoint.

ARB has proposed 40 percent and 55 percent peak smoke opacity cutpoints for the HDVIP. The applicable cutpoint will be determined based on the year model and federal peak smoke opacity certification level of the engine being tested. The 40 percent cutpoint applies to 1974 and newer engines and the 55 percent cutpoint applies to pre 1974 engines. Previous ARB studies (13) concluded that 40 percent and 55 percent cutpoints will result in failure rates of 44 percent and 34 percent, respectively.

Substitution of the current low altitude cutpoints (40 percent and 55 percent) into the aforementioned regression equation (1) results in corresponding high altitude cutpoints of 63 percent and 75 percent opacity. By examining the cumulative distribution chart (Figure 2), the failure rates corresponding to these cutpoints are 46 percent and 39 percent respectively. As can be seen, these failure rates have good agreement with low altitude failure rates. This would result in as many vehicles being identified with excessive smoke at altitudes near 6000 feet (using the 63 percent and 75 percent cutpoints) as would be identified at low altitude (using the 40 percent and 55 percent cutpoints).

Although not adequately investigated, some engine technologies appear to be able to compensate for changes in altitude more effectively than other engine technologies. For example, two DDC Series 60 engines were tested at both TRW and ANW, both engines performed well and had very consistent snap idle results (see Table II). The Series 60 engine is notable because it utilizes an advanced electronic engine control system enabling it to compensate for altitude changes very effectively. In the future, electronic engine controls will most likely be an effective strategy for minimizing altitude effects.

CONCLUSIONS

1. It was found that in-use heavy duty diesel truck engines experience increases in exhaust peak smoke opacity when operated at altitudes near 6000 feet versus sea level.

2. Based on a regression analysis of 80 trucks tested at high altitude and low altitude using a snap idle test procedure, an average increase in smoke opacity of approximately 23 opacity points was observed for the trucks tested.

3. If a high altitude cutpoint were to be chosen for trucks operating at altitudes near 6000 feet, a cutpoint of 63 percent opacity could be applied to 1974 and newer model year engines and 75 percent opacity for pre 1974 engines. These cutpoints would result in failure rates comparable to the those rates observed at sea level using 40 percent and 55 percent cutpoint.

4. Although most of the engines tested showed increases in smoke opacity when tested at high altitudes, engines with advance electronic engine controls appear to be more effective at compensating to changes in altitude.

5. This study was a one site study of a limited number of vehicles and parameters. It is not known to what extent changes in meteorological conditions impact peak smoke opacity levels. Therefore, to fully understand the effects of altitude on peak smoke opacity, further investigation may be needed.

ACKNOWLEDGMENTS

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REFERENCES

1. Notice of Public Hearing to Consider the Adoption of New Regulations Establishing a Roadside Smoke and Emission Control System Inspection Program for In-Use Heavy-Duty Diesel and Gasoline-Powered Vehicles, ARB/Mail-out 90-60, California Air Resources Board, El Monte, 1990, pp.

2. K. Hughes, L. Martz, and J. Denton, Ph.D, The Air Resources Board's Risk Assessment of Diesel Exhaust, California Air Resources Board, Sacramento, CA, 1990.

3. C. S. Weaver, P.E., Inspection and Maintenance for Heavy-Duty Diesel Vehicles, Air Pollution Control Association, March 1987.

4. Ibid 2.

5. Ibid 1.

6. Ibid 1.

7. SAE Handbook, Engines, Fuels, Lubricants, Emissions, and Noise, Vol.3, J 1243, Vol. 3, PA, 1988.

8. Ibid 1.

9. Ibid 7.

10. SAE Handbook, Engines, Fuels, Lubricants, Emissions, and Noise, Vol.3, J 255A, Vol. 3, PA, 1988.

11. C.S. Weaver, R.F. Klausmeier, Heavy-Duty Diesel Vehicle Inspection and Maintenance Study - Final Report Volume III, Radian Corporation, Sacramento, 1988.

12. SAE Handbook, Engines, Fuels, Lubricants, Emissions, and Noise, Vol.3, J 1003, Vol. 3, PA, 1988.

13. Ibid 1.

Table I. Specifications of Truckee Westbound Inspection Facility and the Antelope Westbound Platform Scale.

	Truckee	Antelope
Location	Truckee, California	Sacramento, California
Altitude	5,820 ft Above Sea Level	125 ft Above Sea Level
Highway	Interstate 80 Westbound	Interstate 80 Westbound
Overseeing Agency	CHP	CHP
Facility Type	Inspection Facility	Platform Scale
Approximate Size	600 ft by 250 ft	300 ft by 100 ft
Inspection Bays	4	none
Facility Traffic Flow	350,000 Trucks/Year	200,000 Trucks/Year
Safety Inspections	18,000/Year	900/Year
Hours of Operation	24 Hrs/Day-7 Days/Week	16 Hrs/Day-5 Days/Week
Distance Between Sites	100 Miles	
Approximate Drive Time	1 Hour 50 Minutes	
Test Types Conducted	Snap Idle/Rolling Accel.	Snap Idle
Testing Dates	September 13, 1990 through October 3, 1990	

Table II Results of Trucks Tested at Truckee and Recaptured at Antelope.

MY	MFR	MODEL	HP	DISP(L)	ASP	SNAP IDLE % OPACITY ANW SM	TRW SM	DIF
88	CATE	3406 B	425	14.6	T	12	100	88
89	CATE	3406	400	14.6	T	13	100	87
88	CATE	3406 B	350	14.6	T	17	99	82
88	CATE	3406 B	350	14.6	T	34	100	66
81	CATE	3406 A	400	14.6	T	41	100	60
82	CUMM	NTC 400	400	13.8	T	47	100	53
85	CUMM	NTC 400	400	13.8	T	39	91	52
89	CUMM	NTC 350	350	13.8	T	37	89	52
90	CUMM	LTA 10	300	10.0	T	41	89	48
88	CATE	3406 B	400	14.6	T	18	66	48
*	CUMM	NTC 300	300	13.8	T	30	77	47
87	CATE	3406 B	400	14.6	T	44	86	42
88	CATE	3406	290	14.6	T	27	69	42
85	CUMM	NTC 400	400	13.8	T	48	89	41
90	CATE	3176	325	10.3	T	17	58	41
89	CATE	3406 B	310	14.6	T	37	76	39
87	CUMM	NTC 365	365	13.8	T	32	71	39
88	CATE	3406 B	425	14.6	T	63	100	37
90	CUMM	LTA 10	300	10.0	T	66	100	34
88	CUMM	NTC 315	315	13.8	T	36	68	32
79	CUMM	KT 450	450	1150	T	18	50	32
77	CUMM	NTC 290	290	13.8	T	43	74	31
87	CUMM	NTC 400	400	13.8	T	55	84	29
90	CUMM	NTC 315	315	13.8	T	20	49	29
87	CUMM	NTC 365	365	13.8	T	19	47	28
85	CATE	3406 B	400	14.6	T	66	93	27
90	CATE	3176	325	10.3	T	20	46	26
85	CATE	3208	255	10.4	N	20	46	26
84	CATE	3406 B	400	14.6	T	27	52	25
86	CATE	3406	317	14.6	T	76	100	24
85	CUMM	NTC 300	300	13.8	T	74	98	24
87	CUMM	NTC 350	350	13.8	T	55	79	24
87	CUMM	NTC 350	350	13.8	T	29	52	23
90	CUMM	LTA 10	300	13.8	T	60	82	22
85	IHC	8210C	210	7.6	T	27	48	21
89	CATE	3406 B	425	14.6	T	14	35	21
87	CATE	3406 B	330	14.6	T	80	100	20
83	CUMM	NTC 400	400	13.8	T	30	50	20
89	CUMM	NTC 350	350	13.8	T	23	42	19
88	CUMM	NTC 365	365	13.8	T	13	32	19

MY	MFR	MODEL	HP	DISP(L)	ASP	SNAP IDLE % OPACITY ANW SM	TRW SM	DIFF
89	CUMM	NTC 365	365	13.8	T	12	31	19
89	CUMM	NTC 315	315	13.8	T	22	40	18
87	CATE	3406	425	14.6	T	14	32	18
89	CUMM	NTC 365	365	13.8	T	9	26	17
85	DDC	6V92 TA	340	9.0	T	81	97	16
89	CUMM	NTC 400	400	13.8	T	10	26	16
86	CATE	3406 B	400	14.6	T	50	65	15
89	CATE	3406 B	425	14.6	T	21	36	15
87	CUMM	NTC 350	350	13.8	T	12	27	15
88	FORD	170	170	6.6	T	29	42	14
89	DDC	SERS 60	365	12.7	T	44	57	13
90	CUMM	NTC 365	365	13.8	T	9	22	13
89	DDC	SERS 60	365	12.7	T	46	58	12
89	CATE	3176	325	10.3	T	17	29	12
84	CATE	3406	400	14.6	T	15	27	12
*2	CUMM	NTC 350	350	13.8	T	89	100	11
87	CUMM	NTC 350	350	13.8	T	15	26	11
83	CUMM	NTC 400	400	13.8	T	10	21	11
87	CUMM	NTC 365	365	13.8	T	7	17	10
88	CATE	3406 B	425	14.6	T	47	55	8
87	CUMM	NTC 400	400	13.8	T	22	30	8
84	CUMM	NTC 400	400	13.8	T	16	23	7
84	CUMM	NTC 350	350	13.8	T	13	20	7
85	CUMM	NTC 350	350	13.8	T	10	17	7
88	DDA	6V92 TA	340	9.0	T	94	100	6
86	CATE	3406 B	400	14.6	T	13	19	6
87	CATE	3406 B	400	14.6	T	95	100	5
87	CUMM	NTC 444	444	13.8	T	95	100	5
85	CUMM	NTC 350	400	13.8	T	15	20	5
87	CATE	3406 B	350	14.6	T	92	96	4
89	CATE	3406	350	14.6	T	10	14	4
84	CUMM	NTC 400	400	13.8	T	97	100	3
80	CATE	3406 B	380	14.6	T	97	100	3
86	DDC	8V92 TA	475	12.1	T	98	100	2
89	CATE	3406 B	325	14.6	T	5	6	1
88	CATE	3306 B	300	10.5	T	2	3	1
85	CUMM	NTC 400	400	13.8	T	100	100	0
*	CUMM	NTC 350	350	13.8	T	100	100	0
89	CUMM	NTC 315	315	13.8	T	100	100	0
80	CATE	3406 B	425	14.6	T	18	13	-5

* Engine identification was missing or incomplete.

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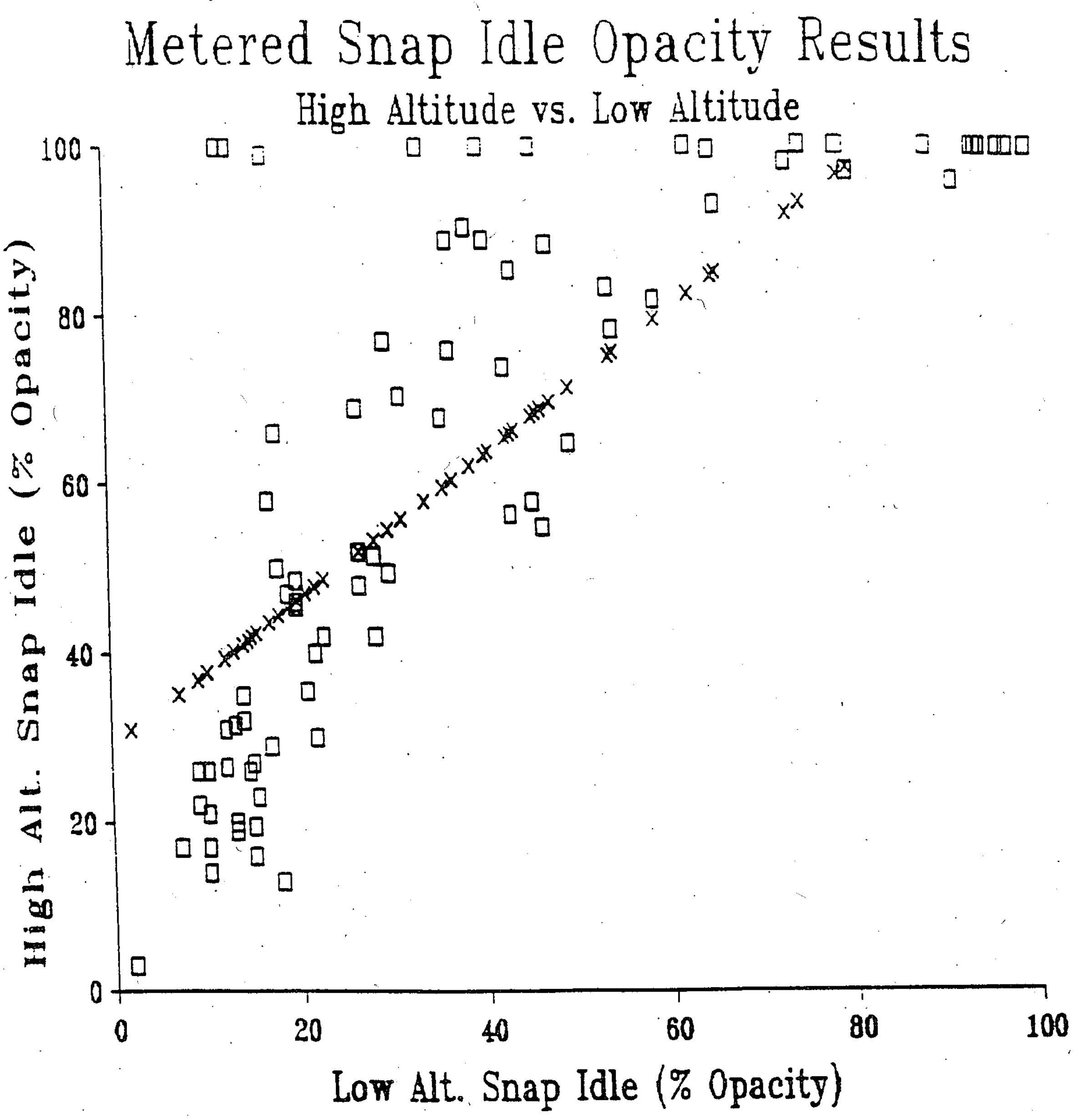

Figure 1. Linear Regression of the average of the two most consistent metered snap idle opacity result for high altitude (TRW) vs. low altitude (ANW). The coefficient of determination (r^2) is 0.619, the correlation coefficient (r) is 0.787, and the y intercept is 29.1.

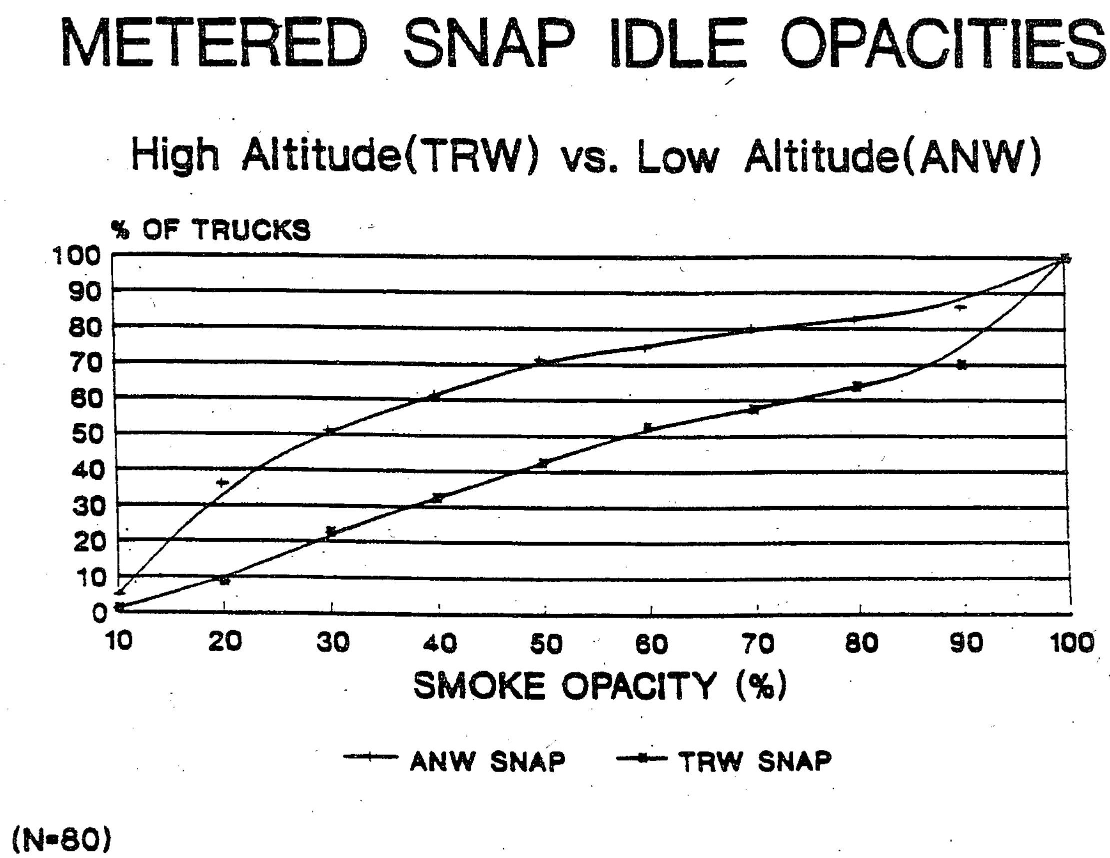

Figure 2. Cumulative distribution chart of the average of the two most consistent peak snap idle smoke opacity values for low altitude and high altitude.