MODEL 107
INFOPAK

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INTRODUCTION

This manual is intended to acquaint you with the Model 107 In-Line Diesel Exhaust Smokemeter by explaining the theory of operation, providing technical descriptions of the unit, smokemeter specifications, installations criteria, and ordering information.

Existing federal regulations have been established on a quality level for exhaust emissions during diesel engine manufacturing. Many state and local agencies, charged with the protection of the environment are implementing regulations that are intended to ensure that a high standard of emissions is maintained throughout the life of the vehicle. Nearly all regulations define diesel exhaust quality in term of the opacity of the smoke plume.

The Model 107 Smokemeter was designed to meet or exceed all performance specifications for diesel exhaust smokemeters advanced by the Society of Automotive Engineers and the International Standards Organization as well as the U.S. Environmental Protection Agency as established by the following:

1. SAE J1157, Measurement Procedure for Evaluation of Full-Flow, Light-Extinction Smokemeter Performance, dated August 1976.
2. SAE J1243, Diesel Emission Production Audit Test Procedure dated October 1978.
3. ISO CD 11614, Apparatus for the measurement of the opacity and for the determination of the light absorption coefficient of exhaust gas from internal combustion engines, dated March 1992.
4. U.S. EPA 40CFR86.884-9, Emission Regulations for Diesel Exhaust Emissions, dated, 1999.
5. 1999/96/EC, European Community Heavy Duty Diesel Exhaust Emissions, dated, 1999.
6. ISO/TC 70/SC 8/WG 1/ N 65, Euro 3 technical annex III, Appendix 4, Section5; General Description of Opacimeter, dated May 1997.

The instrument described herein is designed for use in any of the following three modes:

- Federal cycle opacity measurement for compliance with emission regulations.
- Exhaust emission research and engine design studies.
- Engine production line emission testing and quality assurance.

THEORY OF OPERATION

The basic principle utilized by the Model 107 in measuring smoke density is the attenuation of the intensity of a collimated light beam by smoke aerosol absorption and scattering from a diesel engine exhaust. Measurement is accomplished by passing light pulses through the engine exhaust stream and detecting the loss in light transmission due to exhaust smoke and a photoelectric detector. The relative light energy loss is translated into both OPACITY and SMOKE DENSITY (K) signals, which are displayed digitally at the control unit.

In figure 1, the LED light source of intensity I_0, and condensing lens produce a collimated light beam which passes through the center of the smoke column. Some of the light is absorbed or scattered by smoke aerosols, thus reducing the intensity of the light that reaches the detector focusing lens and the photodiode to I.

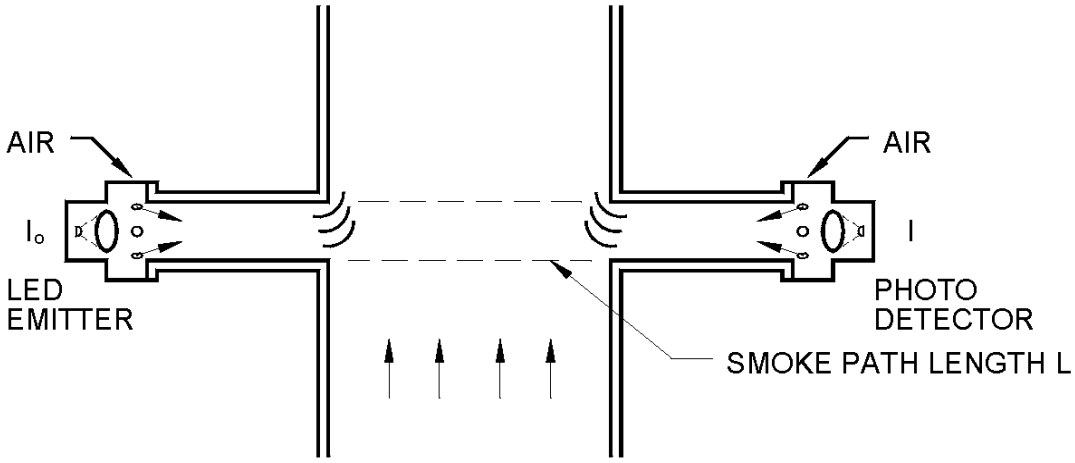


Figure 1

The light intensity reduction can be expressed as:

$$\frac{I}{I_o} = e^{-n\bar{a}\bar{Q}L}$$

Where: n = number density of smoke particles

$\bar{a}$ = average particle projected area

$\bar{Q}$ = average particle extinction coefficient

L = light beam path length within the smoke

A parameter, K, the smoke density, has been defined as : K=naQ

The smoke opacity, defined as one minus the fraction of light transmitted, and the smoke density can thus be related as follows:

$$I/I_0 = e^{-KL} = T/100 - 1 - N/100$$

$$N = (1 - I/I_0)\ 100 = \text{OPACITY (\%)}$$

$$K = (-1)/L)\ \text{Ln}\ (1 - N/100) = \text{SMOKE DENSITY } (m^{-1})$$

The relationship between the Opacity, N, and the smoke density, K, for the various Model 107 exhaust diameters and shown in Table1.

Table 1

Smoke Density K	2" (.0447M)N %	3" (.0701m) N%	4" (.0955m) N%	6" (.137m)*N %	8" (.188m)*N %	10¾" (.254m)*N %	12¾" (.304m)* N%	18" (.432m)* N%	24" (.588m)*N %	28" (.690m)*N %
0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.50	2.2	3.4	4.7	6.6	9.0	11.9	14.1	19.5	25.5	29.1
1.50	6.5	10.1	13.3	18.6	24.6	31.7	36.6	47.7	58.5	64.5
3.50	14.5	21.8	28.4	38.1	48.2	58.9	65.5	78.0	87.2	91.1
10.00	36.0	50.4	61.5	74.6	84.7	92.1	95.2	--	--	--
11.50	40.2	55.3	66.7	79.3	88.5	94.6	97.0	--	--	--

*NOTE: The Effective Optical Path Length (EOPL) is not necessarily the exact I.D. of the stack, due to purge air effects. See following section "Effects of purge air on optical path length".

The purpose of the smokemeter is to measure a characteristic of the engine smoke, inherently relatable to smoke as observed by the human eye. The fundamental characteristic that determines smoke obscuration of light is the smoke density, K; however, this parameter is not independently measurable. The opacity of the smoke on the other hand can be easily measured and the smoke density calculated electronically.

As indicated by the above equation, for a given smoke density the light intensity decreases exponentially with path length. This fact should be kept in mind, if the Model 107 is being used in exhaust lines with an engine port of diameter different that the Smokemeter. As an example, consider an engine with a 2-inch diameter exhaust with the 6-inch diameter M107 suitably attached by means of an expansion section. The smoke density, K107, measured in the 6-inch diameter Smokemeter is the same as K_e, the smoke density of the engine exhaust. However, the measured opacity, N107, will be greater in the Smokemeter than would be measured in the 2-inch engine exhaust line because of the greater path length. If, for instance, the measured opacity is 6.6% in the M107, the engine exhaust opacity is only 2.2% for a 2-inch diameter. Again, this relationship is shown in Table 1.

Effects of Purge Air on Optical Pathlength

The purge air system introduces clean air into the emitter/detector support modules in a way that protects the lenses from smoke deposition and at the same time will not change the smoke light path-length.

The air directed across the lenses, flows through the support tube at a rate, which prevents smoke penetration of the tube, and exhausts into the main exhaust flow. The optimum flow rate for protection without path-length alteration has been experimentally determined to be 3 SCFM (Standard Cubic Feet per Minute).

The purge air velocity entering the exhaust plume is approximately 12 feet per second (1.5 SCFM through each 5/8" port). Smokemeters should be matched to engine sizes that produce velocities greater than 30 feet per second so that the purge air will have no effect on the smoke optical path-length. See Figure 2.

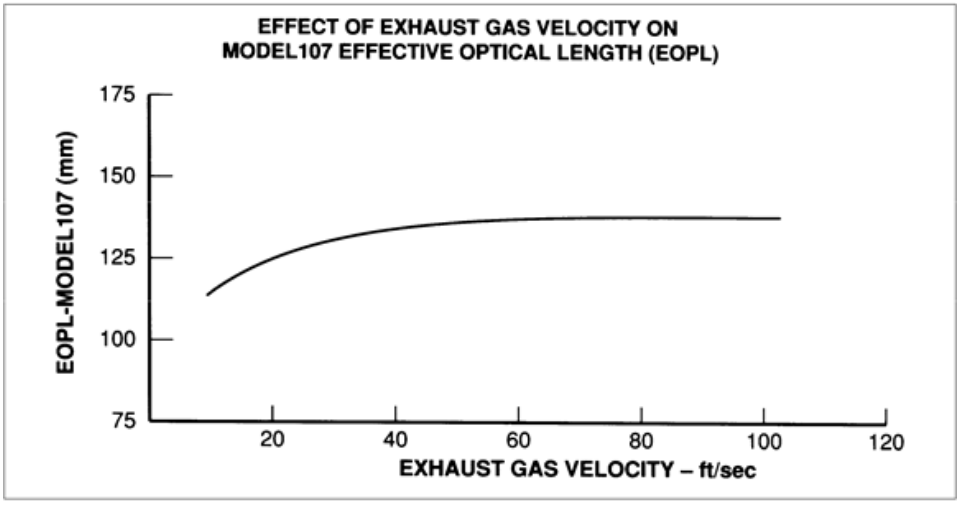


Figure 2

DESCRIPTION

The rugged construction and advanced electronic design make the Model 107 well suited to serve as the standard for measurement of engine emission quality assurance.

The Model 107 Smokemeter consists of the following major components:

- In-line Sensor Unit including emitter/detector modules, sensor module mounts, air purge line and fittings, basic flow pipe with heat shield, pipe flanges for customer welding to mating exhaust line pipe, and clamps for joining flow pipe mating pipes.
- Control Unit including rack mount chassis and power cord.
- Interconnecting Cable (50 ft.) for connecting Control Unit and Sensor Unit electrically.

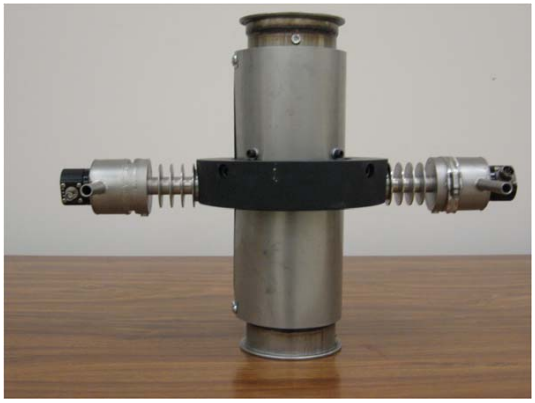
SENSOR UNIT - MECHANICAL

The sensor unit provide a stable mount for the light emitter and detector modules as well as containment of the exhaust gasses as the flow from the engine to the outside atmosphere. The mechanical core basic sensor unit is a can formed of a stainless steel pipe with mounting flanges on both ends for adaptation to the engine exhaust system. The rigid emitter/detector support ring is spring-mounted to the can providing thermal isolation for the optical elements from the hot exhaust flow pipe.

Further temperature isolation is afforded for the optical elements (emitter and detector) by water-cooled sensor mounts which extend radially from the support ring and by a cylindrical stainless steel radiation shield which is mounted concentrically with the basic flow pipe.

Customer supplied clean compressed air is directed across the lenses of the optical system to prevent smoke deposition.

Modular construction allows the sensor unit to be assembled, installed and adjusted easily.



SENSOR UNIT

The mechanical core basic sensor unit is a can formed of a stainless steel pipe with mounting flanges on both ends for adaptation to the engine exhaust system.

The Model 107 is currently available with 2", 3", 4", 6", 8", 10 ¾", 12 ¾", 18", 24" and 28" exhaust can diameters.

Actual can dimensions are as follows:

O.D	I.D.	CAN LENGTH
2" (5.08cm)	1.760" (4.47cm)	15" (38.1cm)
3" (7.62cm)	2.760" (7.01cm)	15" (38.1cm)
4" (10.16cm)	3.760" (9.55cm)	15" (38.1cm)
6" (15.25cm)	5.760" (14.63cm)	15" (38.1cm)
8" (20.32cm)	7.760" (19.71cm)	15" (38.1cm)
10.75" (27.3 cm)	10.482" (26.62cm)	15" (38.1cm)
12.75" (32.39cm)	12.438" (31.59cm)	15" (38.1cm)
18" (45.7cm)	17.624" (44.8cm)	15" (38.1cm)
24" (60.96cm)	23.624" (60cm)	15" (38.1cm)
28" (71.12cm)	27.624" (70.17cm)	15" (38.1cm)

SENSOR UNIT - ELECTRICAL

A light emitting diode (LED), thermal compensator and a collimating lens are mounted in one of the removable sensor modules that extends from the support ring. The LED is rugged, highly efficient and therefore, is not subject to failure caused by vibration or age. A green LED with a maximum light intensity at 570 nm is used, to comply with accepted smokemeter specifications.

A photodetector consisting of a photodiode and a preamplifier is mounted in the other sensor module along with a focusing lens for measurement of the transmitted light. The photodiode is used because of its excellent dynamic range and response, high output and excellent reliability.

The smoke opacity reading is unaffected by background ambient light in the pipe due to the pulsed LED light source, (with an approximated 2% duty cycle at 600 Hz), and the AC coupled photodetector signal within the control unit. The measured photodetector signal thus represents only the pulsed light from the LED. Extraneous light is ignored.

CONTROL UNIT - MECHANICAL

All operating controls and the indicating meter are mounted in a 16" (40.64cm) long x 3" (7.62cm) high x 6" (15.24cm) deep chassis, which is designated for a standard electronic equipment rack mount 19" (48.26cm) long x 3 1/2" (8.89cm) high. The chassis contains a regulated power supply, amplifier, and cable terminations.

MODEL 107 CONTROL UNIT

CONTROL UNIT - ELECTRICAL

The control unit has been constructed for reliability and ease of operation. The unit operates over a wide range of input voltages from 100 VAC to 240 VAC and from 50 to 60 Hz.

PERFORMANCE SPECIFICATIONS

OPACITY SCALE:	0 to 100%
Range	0.1%
Resolution	±0.5% of full-scale opacity due to non-linearity, 24-hour drift, etc., ±0.3% (absolute) during any 4 hour test period.
Accuracy	
SMOKE DENSITY K SCALE:	
Range	0 to 19.99 m^{-1}
Resolution	0.01 m^{-1}
Accuracy	±0.05 m^{-1} to smoke density of 2 m^{-1} ; ± 3% of readings above 2 m^{-1}
READOUT:	3 1/2 Digit Display (Filtered)
RECORDER OUTPUTS:	10 mV per % (Opacity), 0 to 1 VDC Full Scale, 100 mV per m^{-1} (Smoke Density), 0 to >10 VDC Full Scale, Response time, 0.01 seconds to 90%
LIGHT SOURCE:	Light Emitting Diode (GREEN)
Angle of Projection	99% within 3 degrees, half angle
Spectral Output	520 to 610 nm: Peak = 570 nm (GREEN)
Pulse Rate	600 Hz
RECEIVER:	Silicon Photodiode
Angle of View	99% within 3 degrees, half angle
Spectral Response	400 to 1100 nm

Performance Specifications (Continued)

Operating Temperatures:			
Control Unit	10 º C to 50 º C		
Sensor Unit	50 º C Max. Cell Ambient - without cooling water 70 º C Max. Cell Ambient - with cooling water 800 º C Max. Gas Temperature		
Cooling Water	25 º C to 45 º C, with a flow rate of approximately .3 gallons per minute		
Power:	100 VAC to 240 VAC (Selectable), 50 to 60 Hz,10 Watts		
Stack Diameter:	2", 3", 4", 6", 8", 10¾ ", 12¾ ", 18", 24", 28"		
Effective Optical Length:	2" = .0447m	6" = .137m	12¾ = .304m
	3" = .0701 m	8" = .188m	18" = .432m
	4" = .0955m	10¾" = .254m	24" = .588m
			28" = .690m
Control Unit Dimensions:	19" (48.3 cm) wide x 3.5" (8.9 cm) high x 6" (13.6 cm) deep		

Options Available

Linearity Calibration Unit, Option CO-1	In-Situ linearity calibration unit, with 3 neutral density filters (nominal values of 10%, 20% and 40%).
1 Second Bessel Filter for K	Provides an analog output of 0-10 Volts which corresponds to 0-20K. For conformance to Euro III specifications.
ISO-Pak	Gas Temp. probe (TC shielded probe with TC connector), and exhaust gas Pressure Tap. Inclusion of this option allows the unit to meet ISO Smokemeter specifications (ISO 11614).
Correction of K (m^{-1}) To 100 º C Gas Temp:	Corrects K (m^{-1}) Smoke Density to 100 º C Gas Temperature.

Options Available (Continued)

Purge Air Filter:	Norgren F-40-200-AOTA Berkeley P/N 44-0715-01
Purge Air Regulator:	Norgren R11-200-RGL Berkeley P/N 44-0716-01
Recorder Output: **(Opacity):**	0 to 5VDC, Full Scale 1 to 5 VDC, Full Scale 0 to 10 VDC, Full Scale 0 to 5 VDC, 0 to 30% 0 to 10VDC, 0 to 30%

Additional Specification as Required by ISO CD 11614

Exhaust Flow Limits:
Min: 30 ft. per Sec.
Max: None (as long as exhaust gas pressure is maintained to ±1 kPa from P_{atm} practically 100 ft. per Sec.

Exhaust Gas Pressure:
±1 kPa from P_{atm}

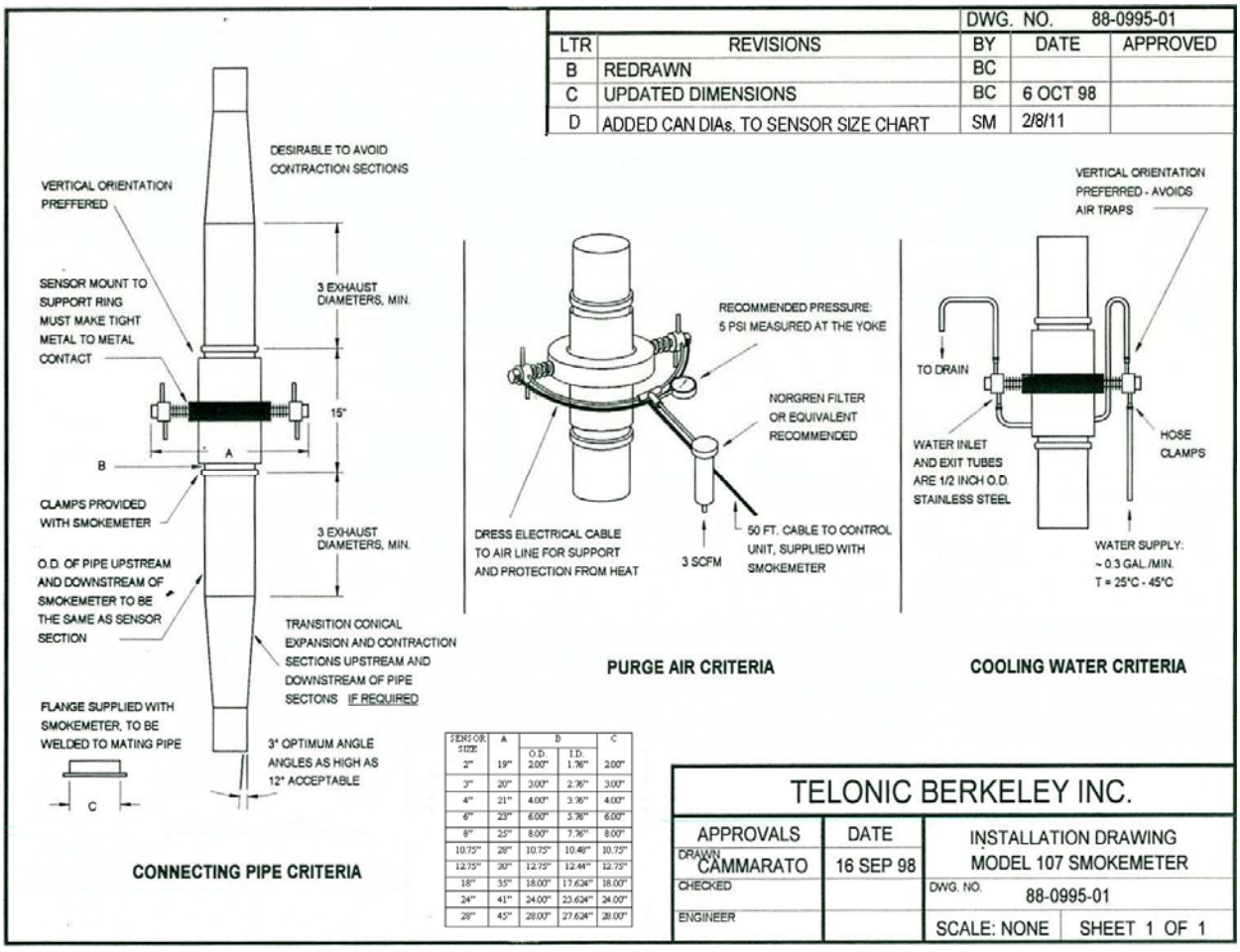
Scavenge Air Pressure:
>4 PSIG <8 PSIG as measured at the "Y" connection to the sensor mounts (see page 13); Flow controlled by design ≈ 3 SCFM (Standard Cubic Feet per Minute).

Physical Response Time:
T_p = <.05 sec.

Electrical Response Time:
T_e = <.01 sec.

Response Time of Temperature Sensor:
(Required for correction of K to 100^0 C)
T_t = $>1^0$ $<2^0$ C/second

Installation Criteria



The installation drawing 88-0995-01 Rev D outlines the important criteria in installing the Model 107 Smokemeter. To install the Sensor Unit in the exhaust system, a straight section of pipe is removed and the adapter flanges are installed so that the spacing between them is 15 inches (38.1cm). The unit is placed in the open section and held in place with the clamps provided. Straight sections of pipe should precede and follow the Sensor Unit to ensure uniform flow conditions in the measuring section. If required, transitions from other size pipes, forward and aft of the straight sections should be made with conical sections using half-angles no greater than 12".

The air supply for the air purge system should be as oil-free as possible with high quality air filters, such as the Norgren filter, installed as close to the Sensor Unit as is practical. The recommended air pressure as measured at the yoke in the air purge line is 5 psi, although pressures as low as 4 psi have been used successfully. The compressor volume flow will be approximately 3 CFM.

MAINTENANCE

The Model 107 Smokemeter is relatively maintenance-free. However, the area requiring the most attention is the sensor modules' air purge system. Oil and moisture filters must be kept in good operating condition. Oil film on the lenses resulting in 1% to 2% opacity is not always visible to the eye. A periodic check and cleaning of the lenses is recommended.

ORDERING INFORMATION

MODEL 107 Control Unit:

- Indicate Line Voltage. Choose From 100v, 220v, Or 240v.
- Choose Can Size And Indicate Vertical Or Horizontal Installation.
- Indicate Required Options From Below.

Opacity Recorder Output Options
(maximum of 2 outputs)

0 - 5 Volt	0 - 100% Opacity
1 - 5 Volt	0 - 100% Opacity
0 - 10 Volt	0 - 100% Opacity
0 - 5 Volt	0 - 30% Opacity
0 - 10 Volt	0 - 30% Opacity

Additional Options:

- Smoke Density (K) Recorder Output
- Temperature T/C Probe and Pressure Tap (Iso-Pak)
- 100° C Gas Temperature Correction Of K
- 1 Second Bessel Filter For K
- C-01 Linearity Calibrator Slide
- Alignment Tube For Optics

SEE PRICE LIST FOR COMPLETE LISTING OR AVAILABLE ITEMS

Order the Purge Air Filter and Regulator separately:

Purge Air Filter:	P/N 44-0715-01	(Order separately)
Purge Air Regulator	P/N 44-0016-01	(Order separately)

Thank you for your interest in our product. Please feel free to contract us for additional information.

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