AP42 Section:	12.2
Reference:	6
Title:	C. Allen, *A Model to Estimate Hazardous Emissions from Coke Oven Doors*, EPA Contract No. 68-02-1408, Docket Item II-A-38 in Docket No. A-79-15, March 1980.

RTI/1736/2-01
March 1980

A MODEL TO ESTIMATE HAZARDOUS EMISSIONS FROM COKE OVEN DOORS

by

C. C. Allen, Jr.
Research Triangle Institute
P. O. Box 12194
Research Triangle Park, NC 27709

EPA Contract No. 68-02-3056

Project Officer

Lee Beck
Industrial Studies Branch
Emission Standards and Engineering Division
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Prepared for

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

ABSTRACT

A mathematical model was developed which relates the emissions from coke oven doors to the percentage of leaking doors and the gap size between the door seal and the oven jamb. Substantial emission reductions (>97 percent) are predicted by enforcement of a 5 percent leaking door standard. Equal particulate emission control is obtained with door hood systems for 23 percent leaking doors, but badly leaking doors cannot be effectively controlled by hoods.

1.0 SUMMARY

The emissions from coke oven doors are difficult to determine experimentally, and even more difficult to correlate with performance information from various emission control techniques. It is necessary to have some method of estimating the quantities of emissions when comparisons between different control strategies are made. A mathematical model has been developed which relates the quantities of emissions to the percent leaking doors on the coke battery.

The method used predicts the percent leaking doors from surface tension effects estimated from oven pressures and gap sizes. The quantity of emissions is estimated from the gap size, oven pressures, and coke oven gas characteristics. Information on the benzene soluble organics (BSO) and benzo-a-pyrene (BaP) content of coke oven gas were developed from ambient sampling data, coal tar analysis, and typical oven gas compositions.

The model predicts substantial reduction in emissions (97.1-99.8 percent) by adherence to a 5 percent leaking door standard when compared with conventional door performance (23-50 percent leaking doors). Equally effective reductions could be obtained for high molecular weight pollutants by using hoods and conventional Koppers door performance (23 percent leaking doors), but the polynuclear aromatics from badly leaking doors could not be effectively controlled with hoods. Benzene and other volatile materials present special oven fume cleaning problems.

This model is considered to represent the best current estimate of coke oven door emissions and is compatible with the best information available on emissions from door closure systems.

2.0 INTRODUCTION

Polycyclic organic matter (POM) includes compounds which are proven carcinogens when applied at elevated levels in laboratory animals. Some of these compounds have been linked with the occurrence of cancer in humans, although it is difficult to establish direct relationships between ambient exposures and carcinogenic effects in man. Many carcinogens have a latent period of several decades, leading to problems of identifying the exposed population, as well as the problem of isolating the effects of a particular ambient carcinogen from other suspected sources of cancer.

The health effects of ambient air concentrations of POM have not been well defined, and, therefore, no safe air concentration can be obtained. The only prudent strategy is to use all practical means to minimize the emissions of POM.[1]

Of particular interest is the polynuclear aromatics (PNA) produced in the reducing atmosphere of the coke oven. Hydrogen is driven off and molecular rearrangements occur in coal during coking which can produce highly active carcinogens. Also, coal tar compounds can serve as co-carcinogens, which induce altered physiological states that may increase the risks associated with other carcinogens. This synergism could in some circumstances greatly increase the health hazard associated with environmental carcinogens.

Benzo-a-pyrene (BaP) is a major component of coke tar (approximately 1 percent) and is associated with particulate emissions of PNA's. A typical coke plant produces 2800 metric tons of coke per day or approximately 155 metric tons of tar and 110 kg BaP per day. This is enough BaP, at the lowest reported dose to induce a carcinogenic response (2 μg/kg), to give an equivalent dose per body weight to 8 million people per battery, per day. Fortunately, the vast majority of BaP which is produced is captured and processed in the by-product recovery plant. This report attempts to quantify the BaP which does escape from the coke ovens and emerges with the yellow-brown smoke, so that the effectiveness of various control strategies can be compared and evaluated.

The evaluation of the severity of emissions from coke oven doors poses an unique problem in emission characterization. Conventional sources of emissions can be characterized by evaluating both the concentration of pollutant and the volumetric flow rate of pollutant. Coke oven doors are unique in that there are multiple sources of emissions, and the emissions from the various sources may be different, both in intensity and concentration. The leaks from the coke oven doors generally are more severe in the beginning of the cycle, diminishing gradually until the tars from the emissions seal the gaps in the metal-to-metal seals. Both the composition of the gases and the magnitude of the leak are expected to vary on an individual door. In addition to this, various doors may have differences in gap sizes which may profoundly influence the quantities of emissions from the various doors.

The conventional method of characterizing the emissions from coke oven doors involves the determination of the percent doors which are leaking (PLD). An estimate of the quantity of emissions is necessary to assess the health hazard from a coke oven battery, particularly when used with computer dispersion modeling. Preliminary indications are that the percent leaking doors can be mathematically correlated with the quantities of emissions from a battery. Theoretical work in this area is presented in this report.

3.0 EMISSION FACTORS

Determination of useful emission factors for coke oven doors is complicated by many factors. Some of the major factors include variability of the emission compositions with time, variable flow rates with time, gap sizes on the seal in use, and factors such as the type of emission control hardware and maintenance. A number of emission factors are presented in Table 1, together with an estimate based upon the model developed in this report. These emission factors are in substantial agreement--the range of the emission factors being much more uniform than anticipated differences between different types of batteries.

TABLE 1. EMISSION FACTORS FROM COKE OVEN DOORS

Reference	Method	Emission factor kg/kg coal	Basis
Kirk[2]	Estimated	<0.006	Particulate
EPA[3]	25 tests	0.00025	BSO[a]
Battelle[4]	Average leakage, 1 door	1.96 SCF/kg coal	Gas
RTI	Model, 23 PLD[b]	0.001 0.28 SCF/kg coal	BSO Gas

[a]BSO-Benzene Soluble Organics [b]PLD-Percent Leaking Doors

Additional information is needed to develop the relationship between BSO and BaP which is present in the emissions. One basic assumption which is necessary to estimate this proportionality is that the composition of gases emitted from the ovens is similar to the composition of gases which are removed from the coke ovens and are sent to by-product processing. Based upon data by RTI and Smith (Table 2) approximately 1 percent BaP is present in the benzene soluble fraction of condensibles from coke oven gas.

TABLE 2. THE RELATIONSHIP BETWEEN THE BENZENE SOLUBLE FRACTION AND (BENZO-a-PYRENE) IN CONDENSATE FROM COKE GAS

	Composition kg BaP/kg BSO	Number of samples tested
NIOSH[3]	0.01	1400
RTI[a]	0.0093[b]	2
EPA[c]	0.0042[b]	5
Smith[5]	0.0129	12

[a]GC mass spectroscopy on coke tar, 2 samples, metallurgical coke.
[b]Assumes 30 percent insolubles in tar.
[c]Activated luminescence, 5 samples, foundry and metallurgical coke.

This agrees with a NIOSH investigation of 1400 samples of coke oven emissions, indicating compatability with the assumption that coke oven door emissions are basically condensed tars. The best estimate of BaP in the BSO is 1 percent.

The composition of coke oven emissions is presented in Table 3. This information was developed from typical compositions of gases treated by the by-product recovery plant. Approximately 15.2 percent of the emissions are assumed to be tar. Since approximately 30 percent of the tar is expected to be insoluble in benzene, the content of precipitating BSO is estimated as 10.6 percent. The quantity of BaP in the coke oven emissions is 0.106 percent based upon 1 percent of BSO. The quantity of benzene in the emissions is estimated as 66 percent of the light oils, or 2.4 percent.

TABLE 3. COKE OVEN EMISSIONS*

Component	Weight (percent)	Molecular weight (gram)	Gram moles (per 100 g)
Water	14.0	18.0	0.78
Oven gas (55% H_2, 28% CH_4, etc.)	64.0	9.8	6.53
Light Oil (benzene, toluene)	3.6	80.0	0.04
Sulfate	3.2	100.0	0.03
Tar	15.2	200.0	0.08
TOTAL	100.0	13.4	7.46

* Estimated as being representative of gas which goes from the coke oven to by-product processing. Assumed to be representative of emissions from leaking doors.

4.0 THE SEALING OF DOOR GAPS BY CONDENSED TARS

Tars condense on the relatively cool door jambs as the coke oven gases pass through small gaps between the sealing edge and the jamb. As these tars accumulate, they either are pushed out of the gap by the escaping gases or will seal the gap if the pressure in the oven is not in excess of the capillary forces of the tar (Figure 1). The capillary forces are generated as the coke oven pressure forms additional surface area. The maximum oven pressure which can be balanced by capillary forces is related to the surface tension (energy per new surface area) and the gap size.

$$\Delta P_m = 2\ \gamma\ G^{-1} \qquad (1)$$

ΔP_m = maximum pressure drop across the gap (dyne cm^{-2})
γ = surface tension (dyne cm^{-1})
G = gap size (cm)

The surface tension of the tar is assumed to be 25 dynes cm^{-1}. When the value for the surface tension is substituted into Equation 1, a relationship is developed which can be used to relate the maximum oven sealing pressure to the gap size.

$$G = 0.02\ \Delta P_m^{-1} \qquad (2)$$

When the oven pressure drops to less than $2\ \gamma\ G^{-1}$, the surface tension of the tar can seal the gap and prevent oven gases from escaping. The length of time required for the oven internal pressure to drop to the sealing pressure is defined as the sealing time t_s. The ratio of the sealing time to the cycle time (t_s/t_c) is then equivalent to the fraction of the time that the oven leaks.

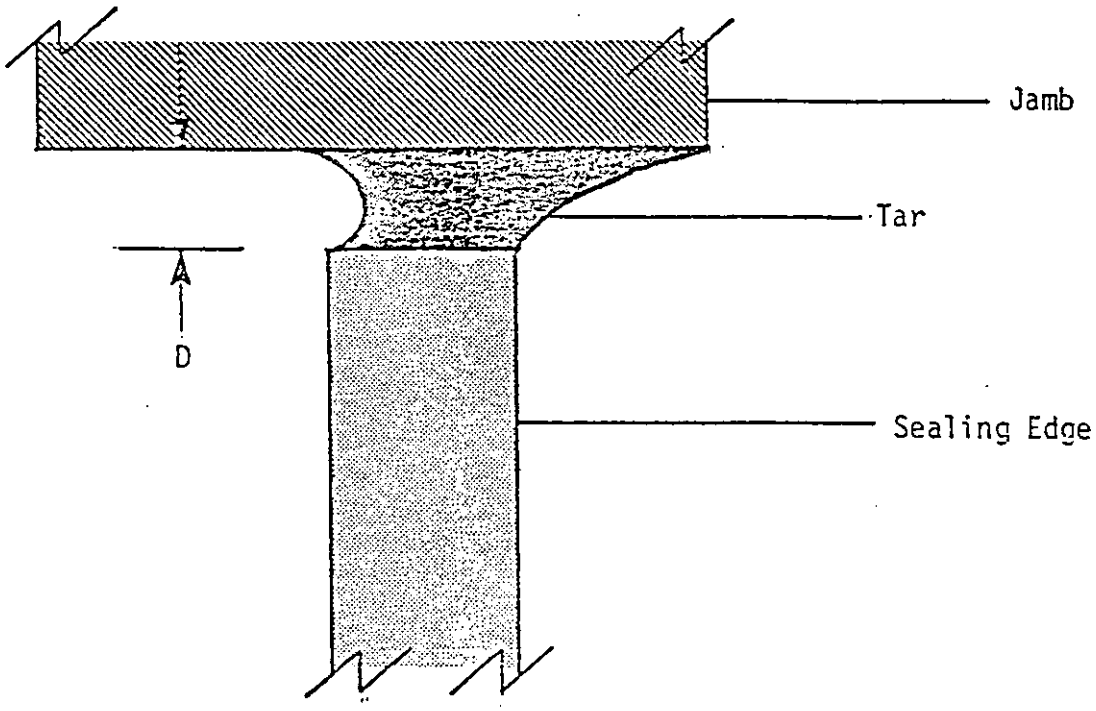

Figure 1. The sealing of gaps by tar.

If it can be assumed that the measurement of percent leaking doors (PLD) is independent of the time during the day at which the PLD determination is made, then the fraction of leaking doors must equal the fraction of the time the typical door leaks. This applies to end doors and not chuck doors. Leaking chuck doors could be considered as a separate source of emissions for the purpose of emission calculations.

$$PLD = t_s/t_c \times 100. \quad (3)$$

PLD = percent doors which have visible emissions
t_c = cycle time of the coking process
t_s = sealing time.

5.0 COKE OVEN DOOR EMISSIONS

Since a positive pressure is maintained in the coke ovens, coke oven gas is invariably emitted from open gaps between the door seal and the oven jamb. The gases, which contain coke tar, pass through the gaps and tars can condense on the jamb and the seal which can be somewhat cooler than the oven gas. The energy from the pressure differential is converted to kinetic energy in the gas flow. The magnitude of this kinetic energy is proportional to the square of the gas velocity passing through the gap for both streamline flow and fully developed turbulent flow. For the special case where the gas flows out of the gap with a relatively low velocity, well developed laminar flow can exist where the velocity is proportional to the pressure drop, rather than the square root of the pressure drop in the former cases.

One type of opening through which turbulent flow has been well characterized is an orifice. The flow rate is proportional to the square root of the pressure drop.[6]

$$W = CA \sqrt{2 g_c \Delta P \rho} \qquad (4)$$

W = flow rate of emissions (lb/sec)
A = area of the orifice (ft^2)
g_c = 32.17 (ft lb/lb_f sec^2)
ΔP = pressure drop (lb_f/ft^2)
ρ = density (lb/ft^3)
C = orifice coefficient (0.61 for well developed turblent flow, relatively small orifice)

The density of the gas may be estimated by assuming a temperature of 316°C, and a molecular weight of 13.5. The estimated properties are summarized in Table 4. The assumed composition of coke oven gases was presented in Table 3.

TABLE 4. ESTIMATED CHARACTERISTICS OF COKE OVEN GAS

Temperature	316°C (600°F)
Density (at 316°C)	205 g/M^3 (0.019 lb/ft^3)
Molecular weight	13.4
Viscosity[3]	0.015 cp (H_2, CH_3, CH_6 at 316°C vary 0.014-016)
Molar volume	10.2 m^3 (360 SCF)
Door perimeter	(9.6 m) (31.5 ft)
Oven charge	14.9 metric tons (16.4 tonnes)

Since a door leaks only on part of the sealing surface, the area of the leaking gaps is assumed to be related to the area in the orifice by the following relationship.

$$A = G\ P\ f \tag{5}$$

G = distance across the gap (ft)

P = perimeter of the coke oven end door (ft)

f = fraction of the door seal which contains gaps (assumed to equal 0.05)

The orifice equation then may be rewritten in terms applicable to a coke oven door.

$$W = 4.89\ G\ P\ f \sqrt{\Delta P\ \rho} \tag{6}$$

For a gap size of 0.08 cm (1/32 inch or 0.0026 ft), a door perimeter of 9.6 m (31.5 ft), a pressure drop of 8 mm water (1.58 lb$_f$/ft^2) the weight rate is 0.0016 kg/sec (0.00347 lb/sec) or 0.16 SCMM (5.5 SCFM). This estimated value is somewhat less than a measured leak rate under these conditions[4] of 0.71-0.85 SCMM (25-30 SCFM).

Equation 6 is simplified by substituting the previously assumed parameters of gas density, door perimeter, and fraction of doors which have gaps of characteristic size G.

$$W = 1.062\ G\ \sqrt{\Delta P} \tag{7}$$

Thus, for the purpose of estimating the emission rate of coke oven gas, the gap size and square root of the oven pressure are the significant variables.

The total emissions from a door during a coking cycle may be obtained by integration of Equation 7 from the beginning of the cycle until the sealing time t_s.

$$E = \int_0^{t_s} 1.062\ G\ \sqrt{\Delta P}\ dt = 1.062\ G \int_0^{t_s} \sqrt{\Delta P}\ dt \tag{8}$$

E = overall emissions, lbs.

The integral of the square root of pressure was numerically determined from data measured for a 6 meter oven (Table 5). The results are presented in Figure 2.

TABLE 5. PRESSURES IN A 6-METER OVEN[7]

Time (min)	Pressure (inches of water)	Pressure (mm of water)
10	10.625	269.87
15	7.82	198.6
20	6.3	160.0
30	4.44	112.8
40	3.4	86.36
50	2.75	69.85
60	2.1	53.34

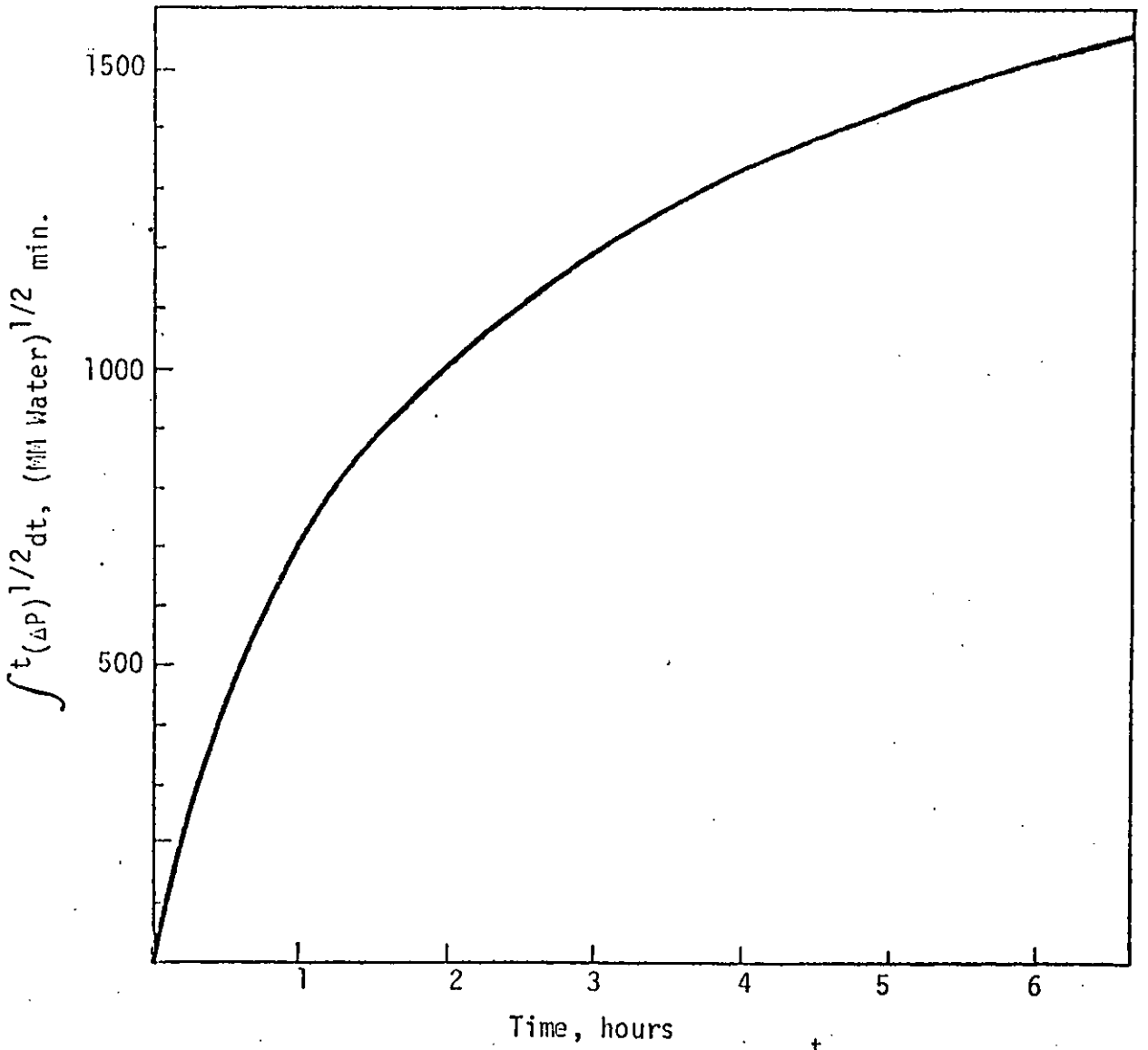

Figure 2. The estimated emission factor, $\int_{o}^{t} \Delta P^{1/2} dt$, for various sealing times on a 6-meter battery.

Sample Calculation

For a typical 17 hours coking cycle, the average door must self-seal after (17 hr) (60 min/hr) (0.05) or 51 minutes to meet a 5 percent leaking door standard. The pressure in a 6-meter oven is 65.4 mm water, 51 minutes after the beginning of the cycle. With a surface tension of 25 dynes cm^{1}, the maximum gap size (from Equation 1) is (50) (65.4 mm water)^{1} (98 dyne/cm^{2} mm water)^{1} or 0.0078 cm. This compares favorably with maintenance specifications of 0.005 cm^{8} and 0.0076 cm^{9} which were needed to achieve 5 percent leaking doors in practice.

The quantity of emissions is calculated by using Equation 8.

$$E = 1.062\,G\int_{0}^{51\ \text{min}} \sqrt{\Delta P}\,dt = \frac{1.062\ (0.0078\ \text{cm})\ (60\ \text{sec/min})(0.452)\sqrt{\frac{\text{lb/ft}^2}{\text{mmH}_2\text{O}}}\ 650\ \text{mm}^{1/2}\ \text{min}}{(2.54\ \text{cm/in})(12\ \text{in/ft})}$$

= 4.8 lbs coke oven gas per charge per door.

6.0 THE RELATIONSHIP BETWEEN PERCENT LEAKING DOORS AND MASS EMISSIONS

The percent leaking doors is a function of the gap size: larger gap sizes between the door sealing edge and the oven jamb require longer times to self-seal. These longer sealing times permit a larger fraction of the doors to leak simultaneously, and careful adherence to maintenance gap specifications is essential for reducing the sealing times. The larger gaps not only permit the emissions to persist longer but also emit more pollutants per unit time.

Equation 9 demonstrates how the gap size may be estimated from the percent leaking doors (PLD).

$$G = 6.5 \times 10^{4}\ \sqrt[3]{PLD} \qquad (9)$$

The emissions may be estimated from the gap size with Equation 8. The results of the calculations are presented in Table 6 and Figure 3 for the model coke oven. From this model, the mass rate of emissions are dramatically affected by the gap size and directly related to the percent leaking doors. Decreasing the percent leaking doors from 25 to 5 percent results in an estimated reduction in emissions of 98 percent, for example.

The relationship between the percent leaking doors and the emissions is presented in Figure 4. The results of the calculations are plotted on a log-log graph and an approximately linear relationship exists between the variables for the PLD range of interest (5-25 percent). The slope of this line is 2.5, implying that the emissions vary with the 2.5 power of PLD. A lesser slope of 1.6 is present for the function at values less than 5 PLD.

The slope of 2.5 can be useful in estimating percent reduction in emissions.

$$\frac{E_1}{E_2} = \left(\frac{PLD_1}{PLD_2}\right)^{2.5} \qquad (10)$$

TABLE 6. THE ESTIMATED EMISSIONS AND PERCENT LEAKING DOORS AS A FUNCTION OF SEALING TIME FOR THE MODEL DOOR SYSTEM

Sealing time (min)	Percent leaking doors (17 hr cycle)	Pressure (mm H_2O)	Gap size (cm)	Total Emissions kg(lb)/door	Total Emissions $\int_0^t \sqrt{\Delta P}dt$ $(mm\ H_2O)^{1/2}$ min	Percent of uncontrolled emissions (34 PLD)
10	1.0	270	0.0019	0.156 (0.344)	191.5	0.06
15	1.5	198	0.00257	0.296 (0.65)	267.7	0.1
20	2.0	160	0.0032	0.46 (1)	334.5	0.2
30	2.9	113	0.0045	0.87 (1.9)	450.0	0.3
40	3.9	86.4	0.0059	1.4 (3.07)	550.5	0.5
50	4.9	69.8	0.0073	2 (4.4)	638.8	0.75
60	5.9	53.3	0.0096	2.96 (6.5)	717.0	1.1
87	8.5	31.0	0.016	5.7 (12.5)	829.0	2.1
144	14.1	12.4	0.041	19.2 (42)	1086.0	7.2
196	19.2	6.2	0.0822	44 (96.8)	1242.0	16.5
259	25.0	3.1	0.165	97.6 (215)	1376.0	36.5
353	34.6	1.2	0.4114	267.2 (588)	1511.0	100.0

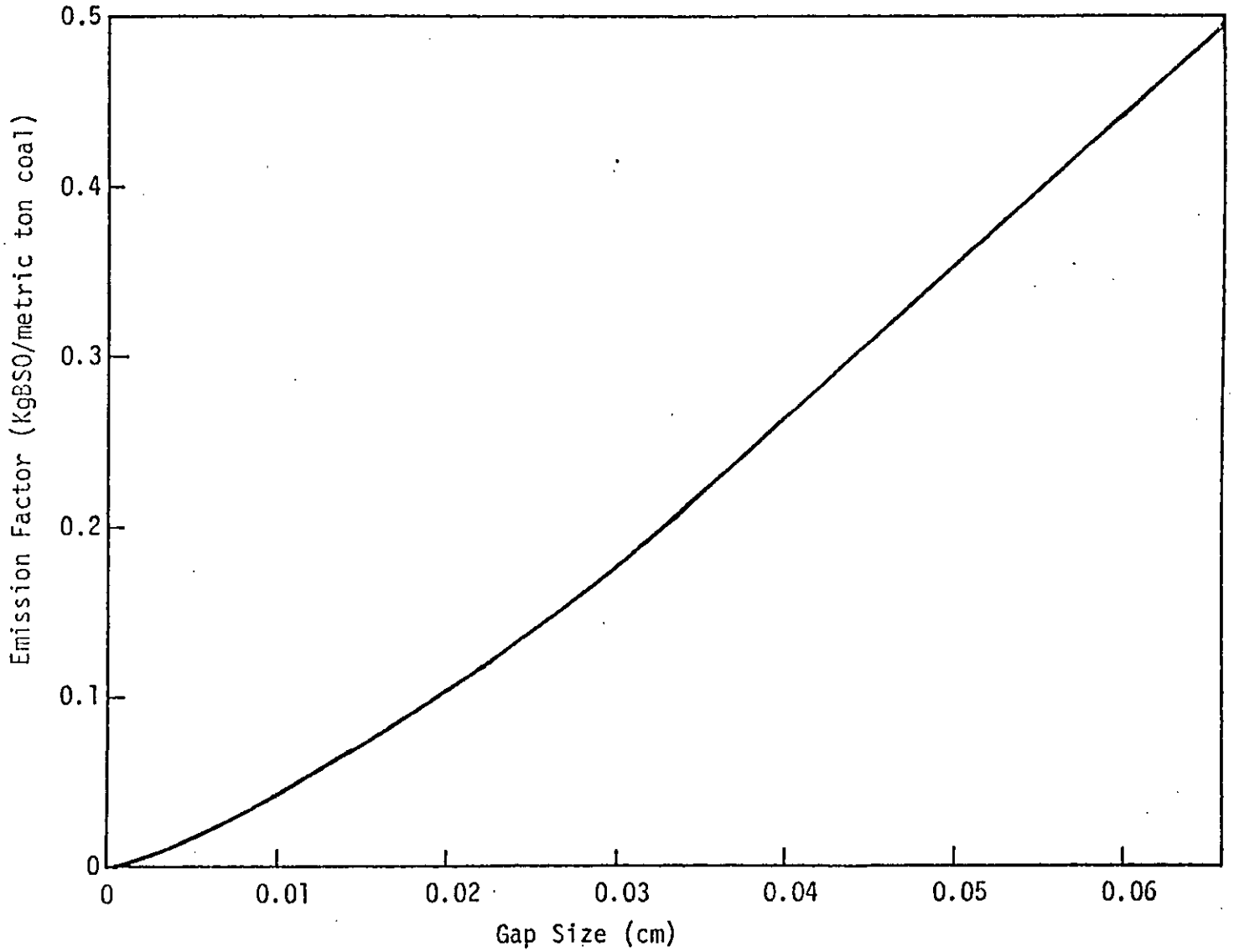

Figure 3. The relationship between the size of the gap of the end door seal and the estimated emissions.

A reduction in PLD from 50 to 5, for example, results in emission reductions of $(0.1)^{2.5} = 0.0032$ or 99.7 percent. From Figure 4, the estimated emissions would be reduced from 840 kg (1848 lb) per door to approximately 2 kg (4.4 lb) per door per cycle, or 99.8 percent.

$R \propto PLD^{2.5}$

$TE = R \times PLD \times N_T \quad \propto PLD^{3.5}$

$* \; TE \propto PLD^{2.5}$

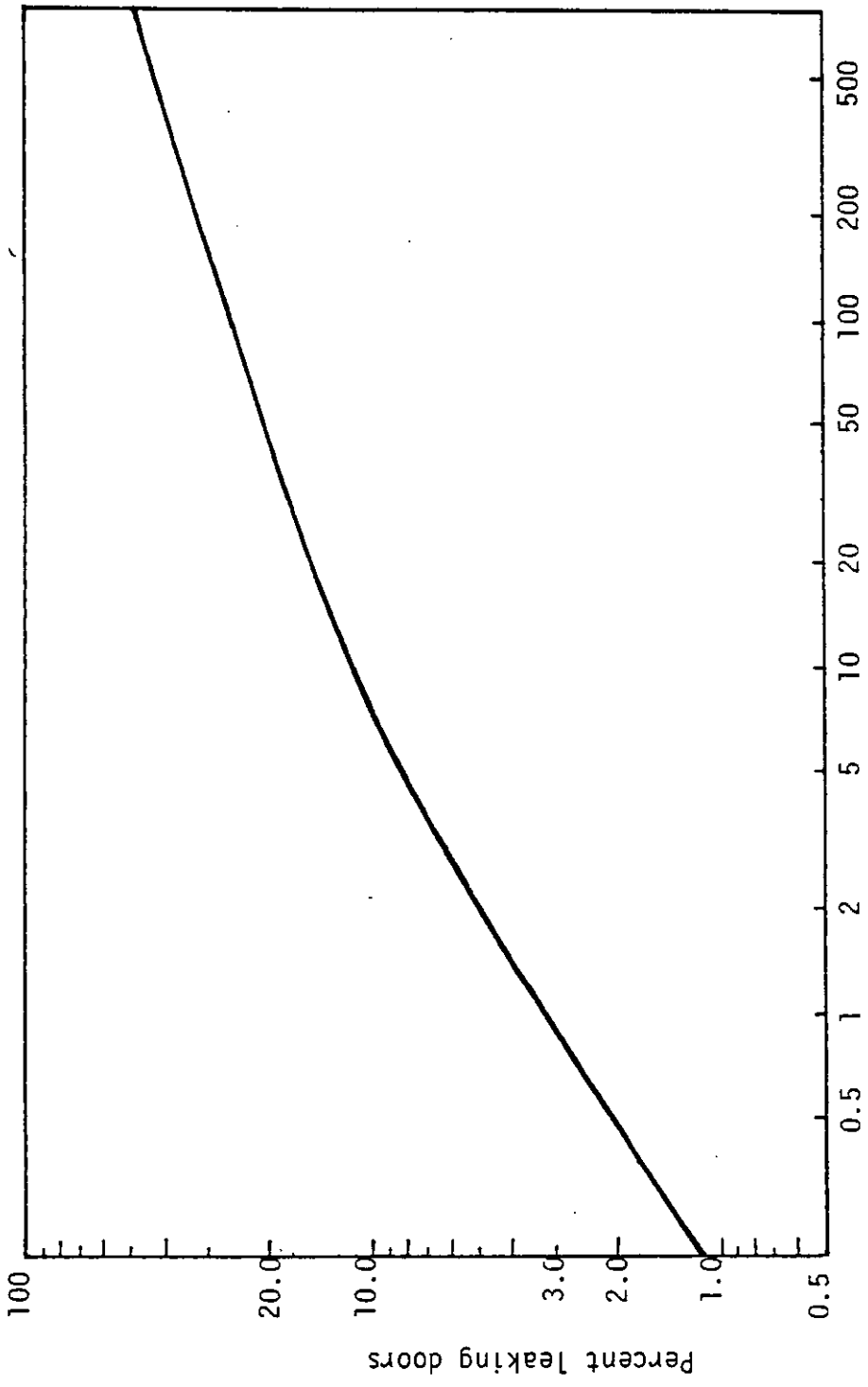

Figure 4. The relationship between the estimated percent leaking doors and the emissions.

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RTI/1736/2-02
MARCH 1980

ESTIMATION OF CHARGING EMISSIONS FOR BY-PRODUCT COKE OVENS

by

Clark Allen
Research Triangle Institute
P. O. Box 12194
Research Triangle Park, N. C. 27709

EPA Contract No. 68-02-3056

Project Officer

Lee Beck
Industrial Studies Branch
Emission Standards and Engineering Division
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

Prepared for

OFFICE OF AIR QUALITY PLANNING AND STANDARDS
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N. C. 27711

ABSTRACT

A mathematical model was developed which predicted that the charging emissions are proportional to the square of the observed charging emission time. This model is based upon the following assumptions:

1. Turbulent flow of the emissions out of the oven.
2. A cyclic variation in the off gases generated during charging which was represented by a sine wave.
3. A constant rate of aspiration during charging, and
4. Similar battery configurations, such as the size of the topside openings which are leaking.

This model predicts that a moderately well controlled battery will have a low emission potential relative to an uncontrolled battery, or a battery not practicing successful stage charging. The emissions were proportional to the square of the time of observed emissions.

1.0 INTRODUCTION

Most coke ovens today are practicing some form of stage charging. Stage charging consists of dumping a prepared coal mixture from a larry car into a by-product slot oven in three or four stages. This controlled placement of the coal mixture into the oven results in a reasonably uniform bed of coal in the oven. This uniform deposition of coal in the oven permits the head space in the oven to remain open so that the hazardous emissions from the coal in the hot oven may be removed, rather than emitted into the atmosphere. These hazardous emissions from the destructive decomposition of coal are generally removed by steam aspiration, although there are several advantages in using weak ammonia liquor for aspiration.

The emissions from the coke oven into the atmosphere specifically depends upon a very large number of factors such as the amount of coal charged, the density of the coal charged, the distribution of the coal in the oven, proper cleaning techniques in the oven and offtakes, the rate of steam aspiration, the size of openings in the oven, the charging rate and other factors. Generally speaking, the situation may be simplified in that the rate of aspiration should be greater than the sum of the off gas generated plus air infiltration.

In spite of the obvious complexity of the situation, a number of assumptions can be made to estimate charging emissions from the battery topside. Two of the major assumptions are that the off gas, which is generated by charging, is generated in a cyclic fashion: that is, the pressure generated during the beginning of a stage in the charging will peak to a high pressure and then will gradually be reduced to a lower pressure as the charging is complete for that stage. Pressure is generated not only from the decomposition of the coal but also the displacement of air in the oven by the coal charged. If insufficient aspiration is present to eliminate all emissions (as is almost always the case), then the oven will become under positive pressure and emissions will escape from any available openings. The magnitude of those escaping emissions depend upon the area available for the pressure release in the oven, the pressure in the oven, and the length of time the oven is under positive pressure.

Based upon this model the emission potential for batteries with a low charging emission time can be compared with batteries with a large charging emission time. It is hoped that these results will assist in the understanding of the relative emission potential from the various types of stage charging performance.

2.0 EMISSIONS MODEL

The rate of generation of gas is assumed to follow a sine wave with time. The rate of gas removal (maximum) is a constant, related to the design and operation of the oven. Additionally, the pressure is assumed to be proportional to the net rate of gas generation and the mass emissions are proportional to the square root of the pressure in the oven (streamline flow or well developed turbulence). Figure 1 presents the idealization of the rate of gas generation with time. The shaded areas represent the time that the oven is under positive pressure, and emissions are possible. Figure 2 shows successful emission control interrupted by an upset (such as an ascension pipe blockage).

A mathematical representation of the functionality of Figure 1 is as follows:

$$R = A \sin(\frac{t}{\tau}) - R_o \qquad (1)$$

R = the rate of generation of excess oven gas (Kg/sec)

τ = the time for a cycle of the sine wave (seconds)

A = the amplitude of the sine wave (Kg/sec)

R_o = the maximum rate of generation of coke oven gas which can be controlled. (Kg/sec)

t = time (seconds)

The pressure in the ovens is considered to be represented by a sine wave. The mass emissions under the conditions of turbulent flow are therefore considered to be proportional to the square root of R.

$$e = K' R^{\frac{1}{2}} \quad (R>0) \qquad (2)$$

e = the rate of emissions (Kg/sec)

K' = a proportionality constant ($Kg^{\frac{1}{2}}/sec^{\frac{1}{2}}$)

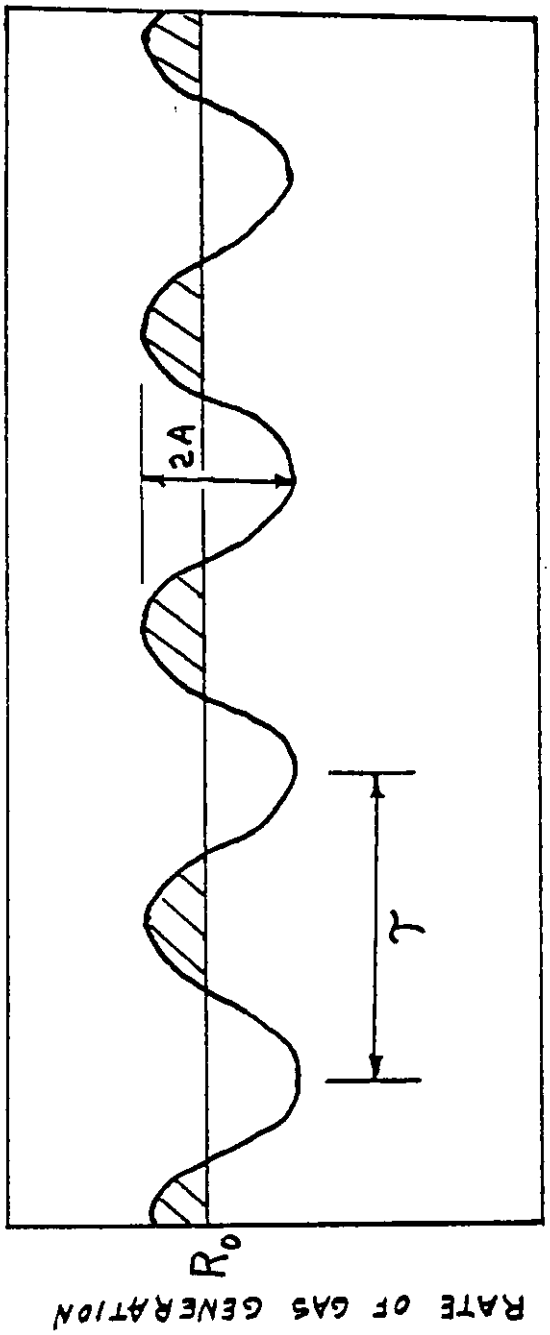

Figure 1. Representation of Charging Control.

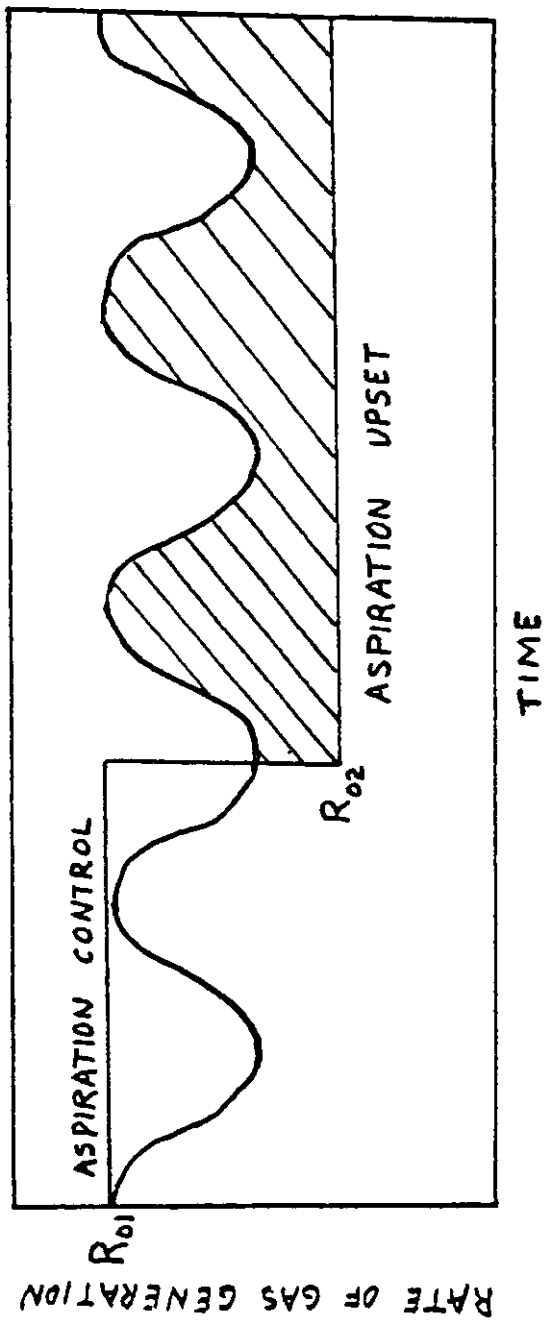

Figure 2. Representation of an Upset in the Aspiration.

Equation 2 may be integrated numerically over the period of time that emissions can occur. Figure 3 presents a sketch of the area of interest. The overall emissions of a cycle are twice the emissions which are calculated from the maximum in the cycle until the emissions cease.

$$E = \int_0^{to} K' R^{1/2} dt = \int_0^{to} K' \left(A \sin \frac{t}{\tau} - R_o\right)^{1/2} dt \qquad (3)$$

note that $A \sin \frac{t_o}{\tau} = R_o$ and $e = o$,

$$R_o / A = \sin \frac{t_o}{\tau}$$

$$E = \tau \int_0^{t/\tau} K' A^{1/2} \left(\sin \frac{t}{\tau} - \sin \frac{t_o}{\tau}\right)^{1/2} d\left(\frac{t}{\tau}\right)$$

$$E = \tau K' A^{1/2} \int_0^{t/} \left(\sin \frac{t}{\tau} - \sin \frac{t_o}{\tau}\right)^{1/2} d\frac{t}{\tau} \qquad (4)$$

Equation 4 was numerically integrated for both the emissions proportional to pressure and the emissions proportional to the square root of pressure. The results are presented in Table 1. The results in Table 1 are consistent with the following relationships:

$$E = k\, t^{3.0} \quad (n = 1.0) \qquad (5)$$

$$E = K\, t^{2.0} \quad (n = 0.5) \qquad (6)$$

E = emissions from a leak (Kg)

K = a constant ($sec^{-2.837}$ in 5, and $sec^{-1.959}$ in 6)

t = time of the leak

n = the exponential dependency of the emissions on the oven pressure.

The values obtained in Table 1 are expected to differ from Equations 5 and 6 slightly due to the errors in the numerical integration technique used. The exponent in Equation 5 was verified with an analytical solution. Equation 6 is the preferred equation since it is expected to be applicable to turbulent flow.

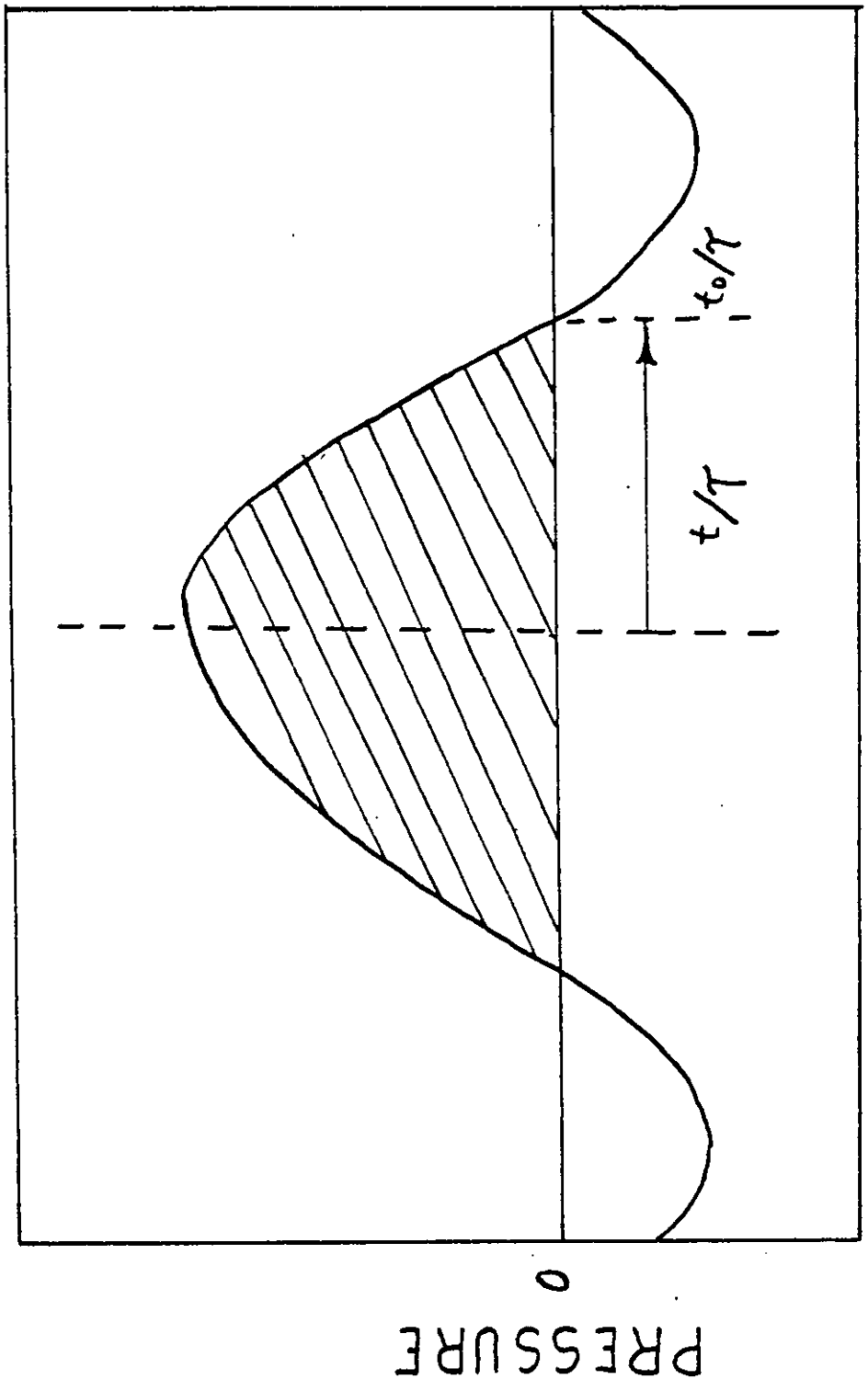

Figure 3. Representation of the Pressures During Charging.

TABLE 1. RESULTS OF NUMERICAL INTEGRATION OF EQUATION 4

$$\int_0^{t/\tau} \left(\sin \frac{t}{\tau} - \sin \frac{t_o}{\tau}\right)^n \, d\frac{t}{\tau}$$

t/τ	$n = \frac{1}{2}$ $\sqrt{P}$ functionality	$n = 1$ P functionality
.1	0.0066	.00044
.2	.0246	.00311
.5	.144	.0436
.7	.275	.115
1.0	.5415	.312
1.2	.758	.5129
1.4		.768
1.5	1.127	
1.57	1.2240	1.025
Exponent[a]	1.959	2.837

[a]Obtained from a log-log plot (slope)

The predictions of Equation 6 are consistent with the comments presented at the NAPTAC meeting July 12, 1978, in Raleigh, North Carolina, by Richard D. Dworek. Movies were shown at the NAPTAC meeting indicating that tremendous quantities of emissions were generated from uncontrolled charging relative to the current levels of stage charging. The results of the model therefore are in substantial agreement with visual observations by trained observers.

3.0 DISCUSSION OF RESULTS

The inertial model (Equation 6) predicts that the charging emissions are proportional to the square of the time of visible emissions. The effectiveness of a control technique to reduce the visible emissions can then be related to the emissions. For example, reducing the charging time by 50 percent would result in an expected reduction in emissions of 75 percent.

The implications of this model may be useful for minimizing some of the negative impacts of stage charging on the coke oven and by-product operation. It may be easily seen from some of the figures that aspiration rates greater than the generation of gases will result in air infiltration. This air infiltration can have a number of detrimental effects in the by-product area. Some of these include sludge formation in the by-product recovery systems, increased problems of gas handling and separation processes in the by-product plant, and additional steam condensate in the tar decanters and waste water treatment systems. Therefore, the rate of steam aspiration should be balanced with the rate of off gas generation for the most effective control of stage charging. If the rate of aspiration could be regulated either automatically or manually, more effective stage charging could be obtained while minimizing the negative aspects of stage charging.

There are potentially severe economic burdens which are expected for some batteries when they achieve the lowest possible level of emission control. This might involve adding additional mains, repaving the battery surface, shutting down the battery and a loss of production during retrofit, and other factors.

Consider a battery with 55 seconds of charging emissions. This battery would have approximately 85 percent control of emissions based upon the estimation of overall industry charging emissions. However, the emissions from this battery still can be reduced by a very substantial amount. Table 2 indicates the relative degrees of control which could be obtained by various performance standards for this battery. It is easily observed in Table 2 that relatively low levels of emissions are obtained for 5 and 12 seconds of charging.

TABLE 2. EMISSION CONTROL ON A BATTERY WITH 55 SECONDS OF CHARGING EMISSIONS

Seconds of charging	Percent reduction
55	0
22	85
12	95
5	99