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PYROLYSIS MODEL FOR AN ALPHA WASTE INCINERATOR PROTOTYPE

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ABSTRACT

The development of a theoretical model of the pyrolysis stage of an SRL prototype alpha waste incinerator is discussed. Pyrolysis rates for single component porous beds of *Teflon* (Registered trademark of Du Pont) and natural rubber have been measured on a bench-scale furnace. Experimental pyrolysis rates compare favorably to the predictions of a quasi-steady regression model. In addition, the pyrolysis rate is shown to be a weak function of the thermal diffusivity of the porous polymer bed. As a consequence, pyrolysis is controlled by thermal degradation kinetics rather than by diffusion or conduction.

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INTRODUCTION

An objective of recent nuclear waste management programs has been to reduce the as-generated and stored volumes of combustible solid radioactive wastes. Combustion methods are advantageous because they not only reduce the volume but also convert the waste to inert or less reactive forms and thereby reduce transportation and storage problems.¹

A program is in progress at the Savannah River Laboratory to develop incineration design technology and to construct a prototype waste incinerator from the Windscale pyrolysis-incinerator concept.² A schematic of the SRL prototype is shown in Figure 1. The incinerator primary consists of a cast refractory cylindrical cavity with an electrically heated *Inconel* (Registered trademark of Huntington Alloys, Inc.) 601 plate. Cylindrical packages of typical waste, containing³ shredded cellulose, polyvinyl chloride (PVC), polyethylene, *Teflon*, rubber, and small amounts of inorganics, will be pyrolyzed in the primary. The incinerator secondary (Figure 1) consists of a labyrinth channel where secondary air is added to the pyrolysis products and the mixture is burned. The secondary is designed to maintain high wall temperatures and to maximize gas residence time by induced turbulence.

The generation of gaseous pollutants such as HCl, HF, NO_x, and CO and particulates is a potential problem. Preliminary work³ was concerned with estimating the exhaust composition from an

optimal incinerator, burning an average mixture of waste, and qualitatively identifying the best overall combustion strategy. This work concluded that the overall pyrolysis process would not be improved by raising the pyrolyzing temperature, but rather by reducing the characteristic length of the solid waste, i.e., reducing the waste porosity. In experiments on a bench-scale model of the SRL incinerator, difficulty was experienced in obtaining ignition of the pyrolysis products of single component porous samples of *Teflon*, neoprene, PVC, and cellulose. In addition, some materials whose pyrolysis products did burn in the secondary, yielded soot and other particulates.

In view of these observations, operation of the incinerator secondary within the flammability limits of the pyrolysis products is an important design constraint. In order to develop experimental flammability limits on the prototype, the pyrolysis rate within the primary must be known as a function of waste composition, waste porosity, and the operating conditions of the primary. It was the objective of this work to develop an analytical model of the pyrolysis process capable of predicting pyrolysis rates as a function of primary design and operating variables. In particular, the role of waste porosity (characteristic length) and primary temperature in determining pyrolysis rates was to be examined.

ANALYTICAL MODEL

As a first approach to the problem, the model was limited to the case of a single polymer waste component. In addition, the geometry of the primary chamber and waste was simplified as shown in Figure 2. Although it is currently anticipated that either a small amount of primary air or nitrogen will be injected into the primary to prevent backflow, pure pyrolysis has been assumed. This assumption limits the heat flux to the polymer surface to net radiation from the walls of the primary chamber.

The pyrolysis of the porous polymer slab was assumed to occur in two stages. A transient heat-up period in which the polymer was considered to be inert, and a quasi-steady regression stage where the polymer regressed at a steady state. Although the porosity of the waste was high (approximately 90% void), the material was assumed to be homogeneous and isotropic.

Transient Heat-Up Period

During the transient heat-up period, the waste was assumed to be stationary, inert, and have constant thermal properties.

The energy equation may be written as

$$\alpha \frac{\partial^2 T}{\partial y^2} = \frac{\partial T}{\partial t} \quad (1)$$

where

$$\alpha = \lambda / \rho C_p \quad (2)$$

The material was assumed to be initially at room temperature, T_{∞}

$$t = 0, \quad T = T_{\infty} \quad (3)$$

Because the polymer was heated on its top surface by radiation from the walls of the furnace,

$$y = 0, \quad \frac{\partial T}{\partial y} = \frac{q_R}{\lambda} \quad (4)$$

In general

$$q_R = \sigma \bar{F}_{ws} (T_w^4 - T_s^4) \quad (5)$$

during the transient heat-up period it was assumed that

$$T_w \gg T_s \quad (6)$$

then

$$q_R \approx q_{R0} = \sigma \bar{F}_{ws} T_w^4 = \text{constant} \quad (7)$$

The temperature at any position in the polymer, y , as measured from the polymer interface was⁵

$$T - T_{\infty} = \left[\frac{q_{R0}}{\lambda} \frac{\phi}{\sqrt{\pi}} \exp \left(- \left(\frac{y}{\phi} \right)^2 \right) - \text{erfc} \left(\frac{y}{\phi} \right) \right] \quad (8)$$

where

$$\phi = \sqrt{4\alpha t} \quad (9)$$

The time for the polymer surface to reach a particular temperature, T_s , was also calculated as

$$t^* = \frac{\pi}{4} \alpha \left[\frac{\rho C_p (T_s - T_\infty)}{\sigma \bar{F}_{ws} T_w^4} \right]^2 \quad (10)$$

Quasi-Steady Regression Stage

It was assumed that regression was steady, the geometry one dimensional, and the polymer surface non-charring. Measuring y as positive outside of the polymer, the following conservation equations⁴ were written.

Species Continuity

$$r \frac{d\rho_i}{dy} = - \frac{d(\rho_i V_i)}{dy} + W_i \quad (11)$$

Energy

$$\left(\frac{dT}{dy} \right) \sum_i \rho_i C_i (r + V_i) = \frac{d}{dy} \left(\lambda \frac{dT}{dy} \right) - \sum_i H_i W_i \quad (12)$$

It was further assumed that all of the reaction would occur at or near the peak temperature ($y = 0$, $T = T_s$). This assumption is valid for polymers which have high activation energies satisfying

$$E/\bar{RT}_s > 20 \quad (13)$$

but may be somewhat in error for char-forming surfaces.

The pyrolyzing material was modeled in two zones, an inert convection-diffusion zone below the pyrolyzing surface and a reaction zone. In the inert convection-diffusion zone, the

condensed phase was assumed to remain intact. Equations 11 and 12 were solved yielding

$$\frac{T}{T_s} = \frac{T_\infty}{T} + \left(1 - \frac{T_\infty}{T_s}\right) \exp\left(\frac{yr}{\rho c_p \lambda}\right) \quad (14)$$

In the reaction zone, a one-step, first-order reaction was assumed

$$w_p = -\rho B \exp(-E/\bar{R}T) \quad (15)$$

The conservation equations were simplified assuming that the polymer in the reaction zone remains intact until it decomposes to monomer, and that convection may be neglected compared to conduction and chemical consumption of energy. The conservation equations were solved⁴ and the regression rate r was determined as a function of the polymer surface temperature T_s .

$$r = \left[\frac{\alpha B \exp(-E/\bar{R}T_s) (\bar{R}T_s E)}{\left[\ln\left(\frac{1}{k_{ps}}\right) + (1 - k_{ps}) \right] \frac{\Delta H_p}{c_p T_s} + \left[\ln\left(\frac{1}{k_{ps}}\right) \right] \left(\frac{T_s - T_\infty}{T_s}\right)} \right]^{\frac{1}{2}} \quad (16)$$

where Lengelle⁶ has determined that

$$k_{ps} \approx 0.01 \quad (17)$$

Equation 16 may be used to determine the regression rate, r , as long as the surface temperature, T_s , is known. Applying mass and energy balance at the surface of the polymer, neglecting conduction on the gas side of the interface,

$$L_s + C_p(T_s - T_\infty) = \frac{q_R}{\rho r} \quad (18)$$

where L_s is the heat of gasification of the monomer.

Substituting Equation 5 into Equation 18 and solving for r ,

$$r = \frac{\sigma \bar{F}_{ws} (T_w^4 - T_s^4)}{\rho [L_s + C_p (T_s - T_\infty)]} \quad (19)$$

By equating Equation 19 and Equation 16, the surface temperature may be determined. Once T_s is known, r may be calculated from either Equation 19 or Equation 16. Finally, the pyrolysis rate may be determined by employing conservation of mass at the interface

$$\dot{m}_p = \rho r A_s \quad (20)$$

where A_s is the polymer surface area exposed to the radiant heat flux.

Theoretical Estimation of Thermal Conductivity

In earlier work on the pyrolysis of solid materials containing voids,⁶ comments by Essenhigh reveal the importance of internal thermal radiation as a mode of heat transfer. Work by Essenhigh⁷ showed that radiation, evaluated using the radiative conductivity approximation, may be many times more important than conduction through the porous bed.

Hager⁸ reported techniques for estimating the effective thermal conductivity of laminar arrays of fibers. The effective

thermal conductivity of a compound slab composed of a layer of solid having thickness Δ and thermal conductivity λ_s and a layer of gas having thickness $1 - \Delta$ and thermal conductivity λ_g was estimated as,⁸

$$\lambda_{eg} = \lambda_g / (1 - \Delta + \frac{\lambda_g \Delta}{\lambda_s}) \quad (21)$$

where Δ may be calculated as the actual density of a pile of solid material divided by the density of the solid. Hager⁸ also reports a contribution to the effective thermal conductivity due to heat flow along the fibers and through points of contact between fibers. Assuming Δ to be small and perfect contact between fibers, Hager⁸ derived the additional term,

$$\lambda_{es} = 4\lambda_s \Delta^3 \quad (22)$$

In a more recent study by Klemens,⁹ the calculation of the radiative component to the effective thermal conductivity was determined for the case of an assembly of fibers of diameter d . In the temperature range of interest in this work

$$\lambda_{er} = 4\sigma n^2 T^3 \frac{d}{\Delta} \quad (23)$$

where σ = Stefan-Boltzmann constant

n = spatial average of the dielectric constant

Summing Equations 21, 22, and 23, the total effective thermal conductivity of an assembly of fibers is,

$$\lambda_e = \frac{\lambda_g}{(1 - \Delta + \frac{\lambda_g}{\lambda_s} \Delta)} + 4\lambda_s \Delta^3 + 4\sigma n^2 T^3 \frac{d}{\Delta} \quad (24)$$

It should be noted that λ_e is temperature dependent by virtue of λ_g , λ_s , and T .

EXPERIMENTAL

The analytical model may be used to calculate heat-up time t^* and pyrolysis rate $\dot{m}_p$ given a temperature independent value for the thermal diffusivity α of the porous polymer. It was the dual purpose of the experiments to determine the thermal diffusivity and pyrolysis rate in an experiment that followed the assumptions of the theoretical model as closely as possible.

Initial experiments were performed with shredded *Teflon* obtained by turning a solid bar of virgin *Teflon* on a lathe. The continuous turnings had a cross section of 0.1 in. wide by 0.001 in. thick. *Teflon* was chosen as the first test material since it is a non-charring polymer that decomposes by a first-order rate law to its monomer, C_2F_4 .

Experimental Apparatus

A schematic of the experimental apparatus is shown in Figure 3. It consists of an electric furnace which was lined with alumina walls. The furnace wall temperature could be varied

to 900°C as measured by an embedded thermocouple whose output was recorded on a strip chart recorder. A vent tube was located in the back of the furnace to allow exhaust of the pyrolysis products when the front door of the furnace was closed. A sample holder which fit snugly into the furnace (Figure 4) was constructed to hold the porous polymer sample. The *Pyrex* (Registered trademark of Owens-Corning) inner container (5.33 cm diameter, 4.32 cm high) which was completely filled with porous polymer was insulated on its sides and bottom by a high-temperature insulation material (1.3 cm thick). This construction promoted one dimensionality. Two chromel-alumel thermocouples were located at known positions in the *Pyrex* container and were used in obtaining experimental thermal diffusivities of the porous polymer samples.

Experimental Determination of Thermal Diffusivity

The temperature of the porous polymer sample at two locations $T_1(y_1)$, $T_2(y_2)$ was experimentally measured during the transient heat-up period (see Figure 5 for typical data). Applying Equation 8 at any time during the transient t_0 and noting that q_{T0}/λ is a constant during the transient

$$\frac{T_1 - T_\infty}{T_2 - T_\infty} = \frac{f(y_1/\phi)}{f(y_2/\phi)} \quad (25)$$

where

$$f(y/\phi) = \frac{1}{\sqrt{\pi}} \exp [-(y/\phi)^2] - (y/\phi) \operatorname{erfc} (y/\phi) \quad (26)$$

and where

$$\phi = \sqrt{4\alpha t_0} \quad (27)$$

Equation 25 was solved for α at a number of times t_0 and averaged. Care was taken in choosing data before the computed heat-up time t^* and yet at times where the temperatures in the sample were significantly greater than T_∞ . Tables 1 and 2 show results for *Teflon* turnings at two furnace wall temperatures, 873 and 1148°K.

Comparison of Experimental to Theoretical Thermal Diffusivities

For the case of a porous bed of *Teflon* turnings, having a density of 0.205 g/cm³ and effective fiber diameter of 0.029 cm, the thermal diffusivity was calculated using Equation 24 along with temperature dependent values of $\lambda_g(\text{air})$, $\lambda_s(\text{Teflon})$, and $C_p(\text{Teflon})$. The result of a comparison of the calculated and measured average values is shown in Figure 6. It was concluded that the thermal diffusivity remains relatively constant during the heat-up period, as was assumed in the model. Investigating the contribution of the three terms of Equation 24, radiation was found to be at least an order of magnitude greater than the other terms, which is consistent with the observations of Essenhigh.^{6,7}

Experimental Pyrolysis Rates

Experimental pyrolysis rates were determined for comparison to the theory. The experimental procedure consisted of weighing

identical samples of *Teflon* turnings after they had been in the furnace at constant furnace temperature for various times.

Pyrolysis was restricted to the top layer of the material, as was assumed in the theoretical model. Experimental results for *Teflon* turnings at various furnace wall temperatures are shown in Figures 7 through 9. Also shown are the theoretical predictions based on the experimental range of thermal diffusivity.

Comparison of Experimental to Theoretical Pyrolysis Rates

In order to calculate the pyrolysis rate $\dot{m}_p$ for the experimental furnace, an angle factor $\bar{F}_{ws}$ was required. The polymer, furnace walls, and sample holder were considered to be two isothermal surfaces and an insulating surface, respectively. The three surfaces complete an enclosure. According to Arpaci¹⁰ the angle factor $\bar{F}_{ws}$ was

$$\bar{F}_{ws} = \left[\left(\frac{1}{\epsilon_w} - 1 \right) + \frac{1}{\bar{F}_{ws}} + \frac{A_w}{A_s} \left(\frac{1}{\epsilon_s} - 1 \right) \right]^{-1} \quad (28)$$

where

$$\frac{A_s - A_w F_{ws}^2}{A_w + A_s - 2A_w F_{ws}} = \bar{F}_{ws}$$

where $F_{ws} = 1$ for a surface enclosed by another surface. The following data was used to determine $\bar{F}_{ws}$

$$\begin{array}{ll} \epsilon_w = \epsilon_{\text{Alumina}} = 0.55 & A_w = 309 \text{ cm}^2 \\ \epsilon_s = \epsilon_{\text{Teflon}} = 0.90 & A_s = 22 \text{ cm}^2 \end{array}$$

The resulting value for $\bar{F}_{ws}$ was 0.296. Using this value, the range of thermal diffusivity determined previously, and the tabulated data for *Teflon* (Table 3), the heat-up time t^* and pyrolysis rate $\dot{m}_p$ were calculated using the analytical model.

The results of the calculations are shown in Figure 10. Sample weight versus time profiles were constructed from Figure 10 and are shown in comparison to the experiments in Figures 7 through 9. Figure 11 shows the computed polymer surface temperature T_s plotted versus T_w . Significant pyrolysis can only occur when there is a significant difference between the furnace wall temperature and the polymer surface temperature.

Comparison of weight versus time obtained by experiment and theory are in good agreement. It was observed that the thermal diffusivity has a strong effect on the heat-up time t^* , but only a weak effect on pyrolysis rate $\dot{m}_p$. Because porosity Δ enters into the calculation of thermal diffusivity through Equation 24, Δ is expected to have a large effect on heat-up time but a negligible effect on the pyrolysis rate $\dot{m}_p$.

Extension of Research to the Case of Natural Rubber

Because the alpha incinerator will be required to incinerate a large quantity (20%) of natural rubber, mostly in the form of shredded (3/4 to 1-in. strips), surgeon's gloves, this material was chosen as the second material to be studied. In a procedure identical to that used for *Teflon* turnings, 20.7 g of rubber strips

was pyrolyzed in the experimental furnace. Weight versus time data, as a function of furnace wall temperature, are shown in Figures 12 through 15. The weight versus time data were fitted to a straight line by the least squares method. The slopes represent the experimental pyrolysis rate at each furnace wall temperature. These experimental pyrolysis rates were then compared to the predictions of the theory as shown in Figure 16.

An attempt was made to experimentally measure the thermal diffusivity of the packed strips of rubber by the technique previously described. Because the temperature at which the rubber surface began to pyrolyze was much lower than for *Teflon*, the recorded temperatures in the sample were very close to the initial temperature during the entire heat-up time. Consequently, accurate experimental measurements of the ratio $(T_1 - T_\infty)/(T_2 - T_\infty)$ were not possible.

Because thermal diffusivity has only a weak influence on pyrolysis rate, an estimated range of thermal diffusivity was used along with the data from Table 3 to calculate pyrolysis rates shown in Figure 16. Natural rubber was assumed to be polyisoprene and was assumed to pyrolyze to its monomer isoprene. Comparison of experimental and theoretical pyrolysis rates was in good agreement.

CONCLUSIONS

The agreement between theory and experiment for the two materials studied indicates that the theory may be used in obtaining reliable estimates of pyrolysis rates in the primary of the prototype incinerator for the case of single component polymer waste. An understanding of the role of thermal diffusivity has been obtained, and the effects of pyrolysis kinetics and the primary wall temperature on the determination of pyrolysis rate were observed. In the incinerator prototype, thermal degradation kinetics, rather than diffusion or conduction, controls the pyrolysis rate, as was maintained in early theoretical work.³

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REFERENCES

1. *Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle*. Vol. 2, Report No. ERDA-76-43 (1976).
2. H. A. Taylor, R. H. Allardice, J. G. Boyle, L. P. O'Connor, and M. J. S. Smith. "UK Experience in the Management of Pu Contaminated Solid Waste." Proceedings of the NEA Seminar at Marcoule, 1974, The OECD Nuclear Energy Agency, Paris, pp. 52-61 (1974).
3. Private Communication, J. M. Tarbell, Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, S. C. (1975).
4. F. A. Williams. "Condensed Phase Mass and Energy Balances" and "Chemical Kinetics of Pyrolysis." Chapters 3 and 4 in *Heat Transfer in Fires: Thermophysics, Social Aspects and Economic Impact*, P. L. Blackshear, Ed., Scripta Book Co. (1974).
5. G. Lengelle. "Thermal Degradation Kinetics and Surface Pyrolysis of Vinyl Polymers." *AIAA Journal* 8 (11), p. 1989 (1970).
6. R. L. Panton and J. G. Rittman. "Pyrolysis of a Slab of Porous Material." *Thirteenth Combustion Symposium*, p. 881, The Combustion Institute (1971).
7. T. P. Stumbar, M. Kuwata, and R. H. Essenhigh. "Flame Spread Through Solid Beds." *Proc. ASME 4th National Incinerator Conference*, Cincinnati, Ohio (1970).
8. N. E. Hager, Jr. and R. C. Steele. "Radiant Heat Transfer in Fibrous Thermal Insulation." *J. Appl. Phys.* 38 (12), p. 4663 (1967).
9. P. G. Klemens and I. N. Greenberg. "Radiative Heat Transfer Through Composite Materials." *J. Appl. Phys.* 44 (7), p. 2992 (1973).
10. V. S. Arpaci. *Conduction Heat Transfer*. Addison Wesley Publishing Co., Reading, MA (1966).
11. K. Raznfevic. *Handbook of Thermodynamic Tables and Charts*. McGraw-Hill, New York (1975).
12. R. E. Bolz and G. L. Tuve. *CRC Handbook of Tables for Applied Engineering Science*. Second Edition, Chemical Rubber Co., Cleveland, Ohio (1973).

13. R. C. Weast. *CRC Handbook of Chemistry and Physics*. Fifty-fifth Edition, Chemical Rubber Co., Cleveland, Ohio (1975).
14. R. E. Schramm. "A Compilation and Evaluation of Mechanical, Thermal, and Electrical Properties of Selected Polymers." NBS Monograph 132 (1973).
15. P. J. Flory. *Principles of Polymer Chemistry*. Cornell University Press, Ithaca, New York (1969).
16. Y. S. Touloukian and D. P. DeWitt. *Thermal Radiative Properties - Nonmetallic Solids*. Plenum Press, New York (1972).

TABLE 1

Experimental Thermal Diffusivity Data

Teflon Turnings $\rho = 0.206 \text{ g/cm}^3$ $T_w = 1148^\circ\text{K}$
 $T_\infty = 14^\circ\text{C}$ $y_2 = 1.78 \text{ cm}$ $y_1 = 0.63 \text{ cm}$

$t_o,$ seconds	$T_1,$ $^\circ\text{C}$	$T_2,$ $^\circ\text{C}$	$\alpha,$ cm^2/sec
19.7	75	25	0.0404
24.6	97	26	0.0271
29.5	122	27	0.0199
34.4	145	29	0.0165
39.3	175	30	0.0132

$\alpha. \alpha_{\text{avg}} = 0.0234 \text{ cm}^2/\text{sec}$

TABLE 2

Experimental Thermal Diffusivity Data

Teflon Turnings $\rho = 0.206 \text{ g/cm}^3$ $T_w = 873^\circ\text{K}$
 $T_\infty = 18^\circ\text{C}$ $y_2 = 1.9 \text{ cm}$ $y_1 = 0.63 \text{ cm}$

$t_o,$ seconds	$T_1,$ $^\circ\text{C}$	$T_2,$ $^\circ\text{C}$	$\alpha,$ cm^2/sec
19.7	64	22	0.0288
39.3	139	26	0.0125
59.0	201	35	0.0100
78.7	248	50	0.0098
98.4	280	67	0.0099
118.0	304	85	0.0102
137.7	320	103	0.0108

$\alpha. \alpha_{\text{avg}} = 0.0131 \text{ cm}^2/\text{sec}$

TABLE 3

Physical and Chemical Data Used in Theory

<i>Text Symbol</i>	<i>Data Units</i>	<i>Teflon (Polytetrafluoroethylene)</i>		<i>Natural Rubber (Polyisoprene)</i>	
		<i>Value</i>	<i>Reference Source</i>	<i>Value</i>	<i>Reference Source</i>
ϵ_s	—	0.90	16	0.86	11
ρ	g/cm ³	0.205	Measured	0.209	Measured
C_p	cal/g-°K)	0.26	5	0.45	3
B	L/sec	4.7×10^{18}	5	9.8×10^{18}	3
E	cal/(g-mol)	8.0×10^4	5	5.6×10^4	3
L_s	cal/g	0	$T_s > T_{crit}$	101	12
λ_g	cal/(cm-sec-°K)	Variable	13	Variable	13
λ_s	cal/(cm-sec-°K)	Variable	14	3.4×10^{-5}	3
ρ_s	g/cm ³	2.2	5	0.91	3
n	—	2.04	13	3.0	13
ΔH_p	cal/g	Variable	5	263	15

FIGURE 1. Schematic of Alpha Incinerator Prototype

T_w = Wall Temperature
 A_w = Wall Area
 ϵ_w = Wall Emissivity
 T_s = Surface Temperature
 A_s = Surface Area
 ϵ_s = Surface Emissivity

FIGURE 2. Simplified Geometry of Primary

FIGURE 3. Experimental Apparatus

FIGURE 4. Section View of Sample Holder

FIGURE 5. Typical Data

FIGURE 6. Thermal Diffusivity for *Teflon* Turnings

FIGURE 7. Pyrolysis of *Teflon* Turnings
 $T_w = 873^\circ\text{K}$

FIGURE 8. Pyrolysis of *Teflon* Turnings
 $T_w = 1023^\circ\text{K}$

FIGURE 9. Pyrolysis of *Teflon* Turnings
 $T_w = 1148^\circ\text{K}$

FIGURE 10. Pyrolysis of *Teflon* Turnings

FIGURE 11. Pyrolysis of *Teflon* Turnings

FIGURE 12. Pyrolysis of Rubber Gloves
3/4" to 1" Strips
 $T_w = 723^\circ\text{K}$

FIGURE 13. Pyrolysis of Rubber Gloves
 3/4" to 1" Strips
 $T_w = 873^\circ\text{K}$

FIGURE 14. Pyrolysis of Rubber Gloves
 3/4" to 1" Strips
 $T_w = 1023^\circ\text{K}$

FIGURE 15. Pyrolysis of Rubber Gloves
3/4" to 1" Strips
 $T_w = 1123^\circ\text{K}$

FIGURE 16. Pyrolysis of Rubber Gloves
3/4" to 1" Strips

APPENDIX

NOMENCLATURE

- A_s - polymer surface area exposed to the radiant heat flux
- A_w - surface area of furnace walls above polymer surface
- B - pre-exponential factor for pyrolysis process
- C_i - specific heat at constant pressure of species i
- C_p - specific heat at constant pressure of the polymer
- d - effective fiber diameter
- E - activation energy of pyrolysis process
- $\bar{F}_{ws}$ - angle factor between the primary walls and the surface of the polymer
- H_i - enthalpy per unit mass for species i
- K_{ps} - the ratio of the density of the polymer at the surface to the density of the polymer far from the surface
- L_s - heat of gasification of the monomer at the surface temperature T_s
- $\dot{m}_p$ - rate of mass loss of polymer due to the pyrolysis process
- n - spacial average of the dielectric constant
- q_R - net heat flux to the surface of the polymer from the walls of the primary
- q_{R0} - defined by (EQ7)
- r - regression rate
- $\bar{R}$ - universal gas constant
- t - time
- t^* - time for the polymer surface to reach a temperature T_s
- T - temperature
- T_s - temperature of the polymer surface during quasi-steady regression
- T_w - temperature of the primary walls
- T_∞ - initial temperature of the polymer

- v_i - velocity of species i with respect to that of the non-degraded polymer
- w_i - mass of species i produced per unit volume per second by chemical reactions
- w_p - mass of polymer consumed per unit volume per second by chemical reactions
- y - spacial coordinate
- α - thermal diffusivity of the porous polymer
- Δ - ratio of the density of the porous polymer to the density of solid polymer
- ΔH_p - heat of depolymerization
- λ - thermal conductivity of the porous polymer
- λ_e - effective thermal conductivity of an assembly of fibers
- λ_{eg} - defined by EQ21
- λ_{es} - defined by EQ22
- λ_{er} - defined by EQ23
- λ_g - thermal conductivity of gas component of porous polymer
- λ_s - thermal conductivity of solid polymer
- ρ - density of the porous polymer
- ρ_i - density of species i
- ϕ - defined by (EQ9)
- σ - Stefan-Boltzman constant
- ϵ_s - emissivity of polymer surface
- ϵ_w - emissivity of furnace surface