BELLCOMM, INC.
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SUBJECT: Briefing to OART on Our Activity in Combustion Analysis - Case 320

DATE: November 12, 1968

FROM: M. V. Drickman

MEMORANDUM FOR FILE

Copies of Vu-graphs presented to the Office of Advanced Research and Technology (OART) on November 4, 1968, are attached. The presentation had been suggested by B. Achhammer to familiarize OART with the work of S. Fineblum and myself on the problems of combustion and flame propagation in spacecraft.

NASA attendees were B. Achhammer, Dr. I. Weinberg, G. Deutsch, I. Schwartz, J. Howe, J. Gangler, W. Steinle, J. Enders, Dr. H. Kurzweg, and Dr. C. Dunn, a consultant from Rochester. The Bellcomm attendees were M. Drickman, S. Fineblum, J. Saxton, and G. Troussoff.

M. V. Drickman

2033-MVD-mrs

M. V. Drickman

Attachments:
Introduction Vu-graphs 1 thru 4
Figures 1 thru 8
Figures FP-1 thru FP-24

(NASA-CR-100221) BRIEFING TO OART ON OUR ACTIVITY IN COMBUSTION ANALYSIS (Bellcomm, Inc.) 36 p

N79-72603

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SOME MAS/BELLCOMM POST-FIRE TASKS

- CONTRIBUTE TO NEW MATERIAL SPECIFICATIONS
- MONITOR MATERIAL SUBSTITUTION PROGRAM
- MONITOR TEST PROGRAM

Introduction Vu-graph 1

APOLLO EFFORT

- MASSIVE TESTING PROGRAM
  - 3,000 <u>SAMPLES</u>
- PROGRESSIVE AND REPEATED TESTS
  - SAMPLE
  - COMPONENT
  - INSTALLED FULL SCALE

Introduction Vu-graph 2

APOLLO PROGRAM EXPERIENCE

RESULTS AT GREAT COST

- SUCCESS IN FULL SCALE TESTS OF SPACECRAFT UNDER OPERATIONAL CONDITIONS

PROBLEM

- "SURPRISES" AND INCONSISTENCIES

UNFINISHED BUSINESS - EXTRAPOLATION

- O_2 CONCENTRATION VARIATION
- OFF-NOMINAL CONDITIONS
- ACCELERATION FIELDS
- NEW MATERIALS

Introduction Vu-graph 3

BELLCOMM APPROACH

COMBINE

- APOLLO PROGRAM OFFICE SUPPORT
- EFFORT TO GAIN UNDERSTANDING OF COMBUSTION PROCESSES
    - IGNITION
    - PROPAGATION

Introduction Vu-graph 4

QUALITATIVE SCHEME OF POLYMER COMBUSTION

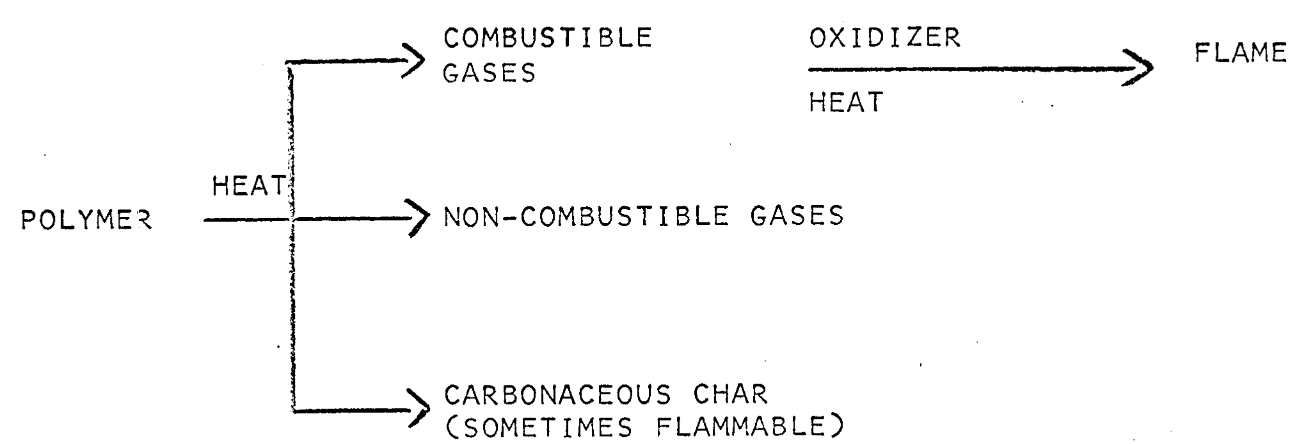


Figure 1

ASPECTS OF COMBUSTION WHICH SHOULD BE WELL CHARACTERIZED:

REACTION KINETICS*

FLUID DYNAMICS

THERMODYNAMICS

MASS TRANSPORT

ENERGY EXCHANGE

* PRIMARY INTEREST OF THE CHEMIST

Figure 2

REACTION KINETICS:

- RATES OF DIFFERENT CHEMICAL REACTIONS INVOLVED
- REACTION PATHWAYS
- DEPENDENCY OF RATE ON THE NATURE OF THE MATERIAL *
- DEPENDENCY OF RATE ON THE NATURE OF THE ENVIRONMENT, E.G., OXYGEN PRESSURE

Figure 3

TWO CHOICES:

1. SYSTEMATIC INVESTIGATION INTO THE RELATIONSHIP BETWEEN CHEMICAL COMPOSITION AND STRUCTURE AND PROPERTIES

2. INDISCRIMINATE TESTING WITH EVALUATION BASED ON COMPARISONS OF DATA WHICH ARE NOT REALLY UNDERSTOOD

CHOICE 1 WOULD BE HELPFUL IN DEVELOPMENT OF CRITERIA FOR MATERIALS DESIGN, TESTING, AND SELECTION.

CHOICE 2 COULD BE A USEFUL SCREENING CRITERION IF METHODS STANDARDIZED COULD OBTAIN USEFUL INFORMATION SHORT-TERM RESULTS.

Figure 4

THERMALLY STABLE MATERIALS TEND TO BE NON-FLAMMABLE

EMPIRICAL SEARCH FOR THERMALLY STABLE MATERIALS HAS CENTERED ABOUT THE FOLLOWING TYPES OF POLYMERIC SYSTEMS:

- AROMATIC
- HETEROCYCLIC
- CHELATE
- SILICON
- ORGANO-METALLIC
- INORGANIC

Figure 5

AROMATIC AND HETEROCYCLIC POLYMERS:

MORE HEAT RESISTANT THAN OTHER ORGANIC POLYMERS

LESS FLAMMABLE THAN OTHER ORGANIC POLYMERS

WHY?

Figure 6

ENHANCED STABILITY OF AROMATIC POLYMERS

DUE TO ELECTION DELOCLIZATION

SOME ELECTRONS NOT LOCALIZED ON AN ATOM OR BETWEEN TWO ATOMS, BUT ARE FREE TO MOVE OVER EXTENDED PORTIONS OF A MOLECULE

LOWERS INTERNAL ENERGY OF THE SYSTEM

INCREASES STABILITY OF THE SYSTEM

Figure 7

IMPLICATIONS

CAN EXPLAIN OBSERVED STABILITY OF OTHER TYPES OF POLYMERS USING CHEMICAL ARGUMENTS

HAVE CAPABILITY OF DESIGNING MATERIALS TO FULFILL SPECIFIED CRITERIA

HAVE CAPABILITY OF DEVELOPING TEST METHODS WHICH ARE MEANINGFUL AND RELIABLE

Figure 8

PRELIMINARY FINDINGS -

FLAME PROPAGATION DEPENDENCE ON ATMOSPHERIC OXYGEN

FP-1

REQUIREMENTS FOR PREDICTIONS OF VARIATION

- EXTEND SAMPLE TEST RESULTS TO OPERATIONAL CONDITIONS
- TO RATIONALLY SELECT CHAMBER CONDITIONS

FP-2

VARIATION OF FLAME SPREAD VELOCITY WITH O_2 CONCENTRATION

- GENERALLY KNOWN AS POSITIVE ONLY

- NO DEPENDABLE BASIS FOR PREDICTION

FP-3

POWER LAW

CORRELATION BETWEEN FLAME SPREAD VELOCITY ALONG SOLID

$$r \sim (O_{2MF})^{m}$$

$$r \sim (O_{2MF}^{n}\, P)^{m'}$$

$$r \sim (O_{2MF}\, P)^{m}$$

FP-4

DATA OF AEROSPACE MATERIALS DID NOT FIT

- MSC
- USN
- NAR

FP-5

SIMPLE POWER LAW

a. DID NOT FIT

b. COULD NOT ACCOMMODATE ZERO FLAME SPREAD

IMPROVED POWER LAW

$$r = a \log \left\{ \frac{p^m}{(C_p)_{O_2} + n\,(C_p)_X} \right\} + b$$

r = rate of flame propagation

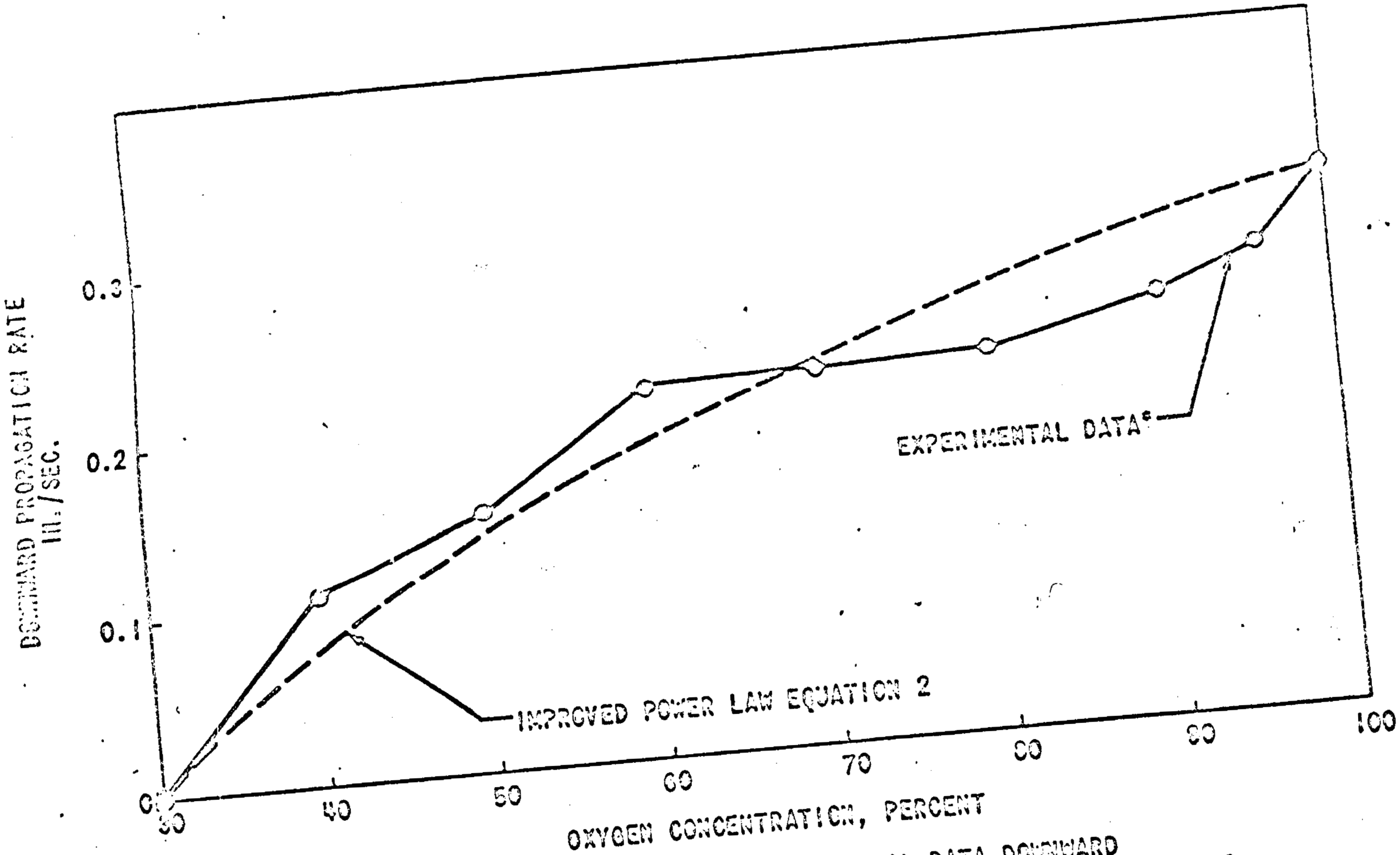
C_p = molar specific heat

n = ratio of diluent-to-oxygen

P = pressure in atmospheres

TYPICAL CURVE

- INITIAL SHARP INCREASE
- FLATTENING
- INCREASED ACCELERATION



SHEET 5 - POWER-LAW EQUATION AND EXPERIMENTAL DATA DOWNWARD PROPAGATION OF 0.005 INCH NOMEX IN VARIOUS O_2/N_2 MIXTURES AT A TOTAL PRESSURE OF 16.5 PSIA

*EXPERIMENTAL DATA FROM NASA MSC (REFERENCE 17)

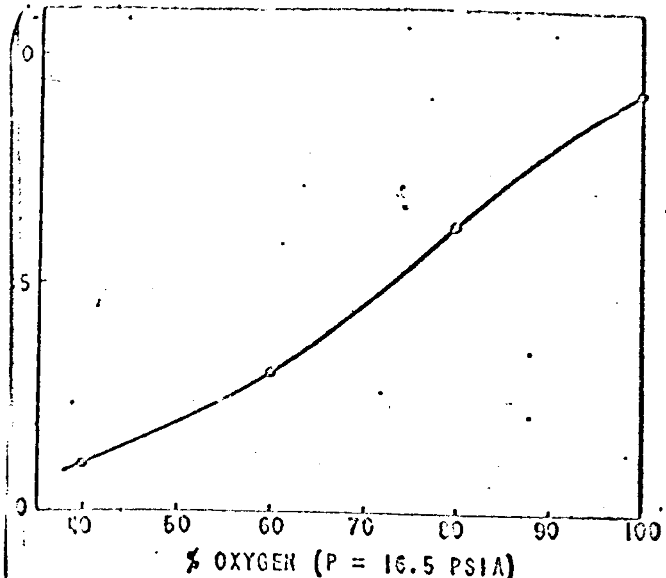


FIGURE 2 - COMBUSTION RATE OF RTV 560/577 (85/15) SILICONE ELASTOMER BLEND (0.125-IN. THICK) (REF. 9)

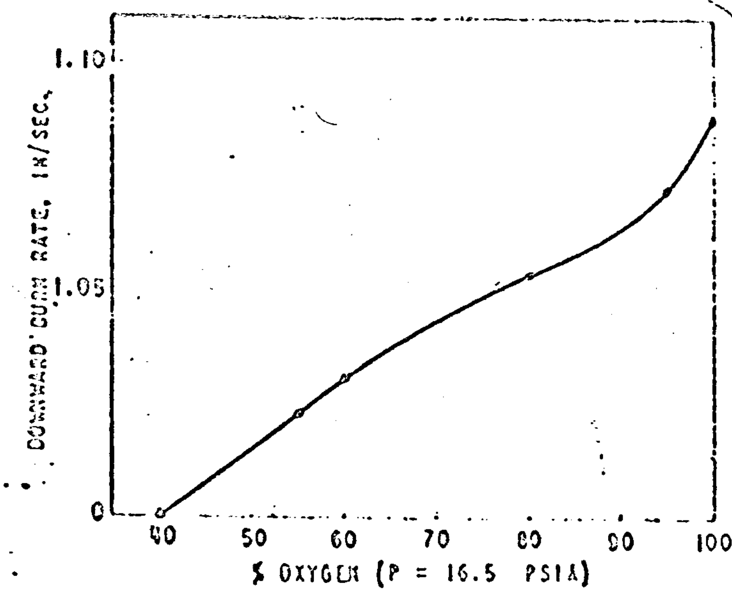
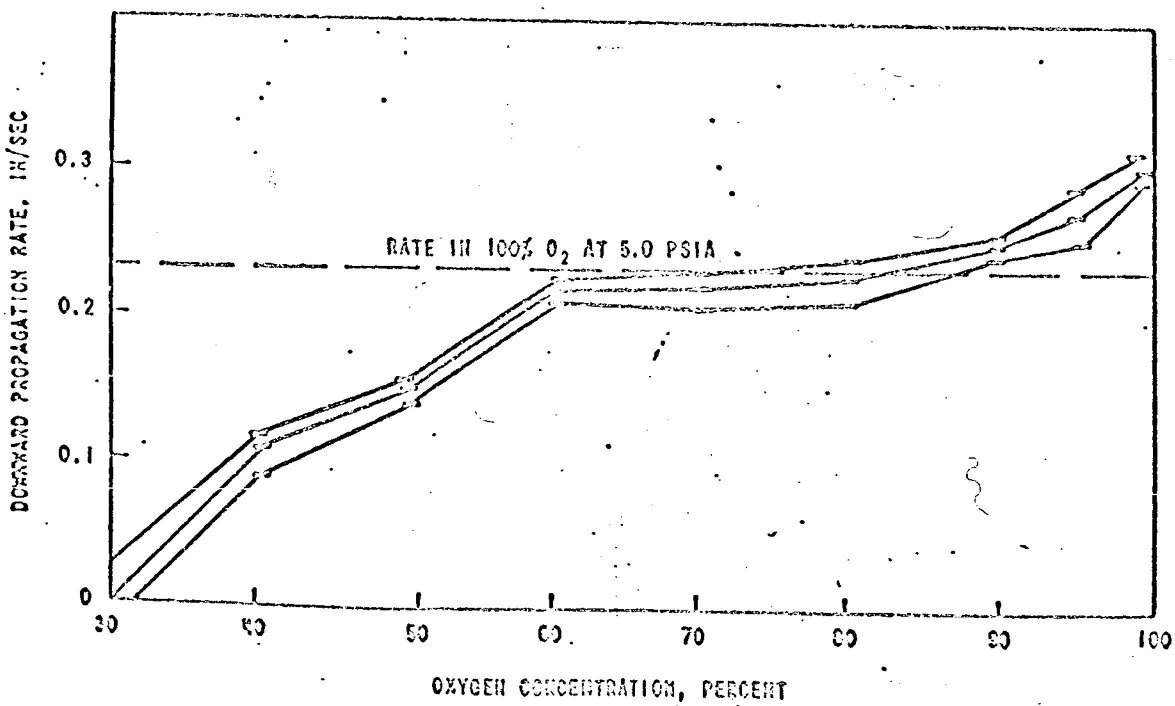


FIGURE 3 - COMBUSTION RATE OF RL 2060 FLUOREL SPONGE (0.23-IN. THICK) (REF. 9

FP--10

FIGURE - DOWNWARD PROPAGATION OF 0.005 INCH NOMEX IN VARIOUS O_2/N_2 MIXTURES AT A TOTAL PRESSURE OF 16.5 PSIA



SHEET 1 - BURNING DOWNWARD (9 & 17)

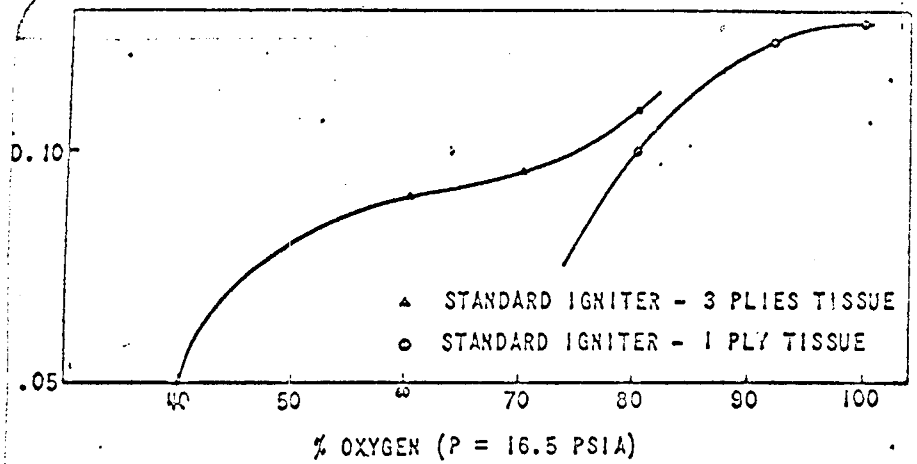


FIGURE 5 - COMBUSTION RATE OF DC 7141 SILICONE RESIN/181 GLASS FABRIC LAMINATE (0.040-IN. THICK) (REF. 9)

FIGURE 4 - COMBUSTION RATE OF TEFLON, TYPE E-7A (10-MILS THICK)

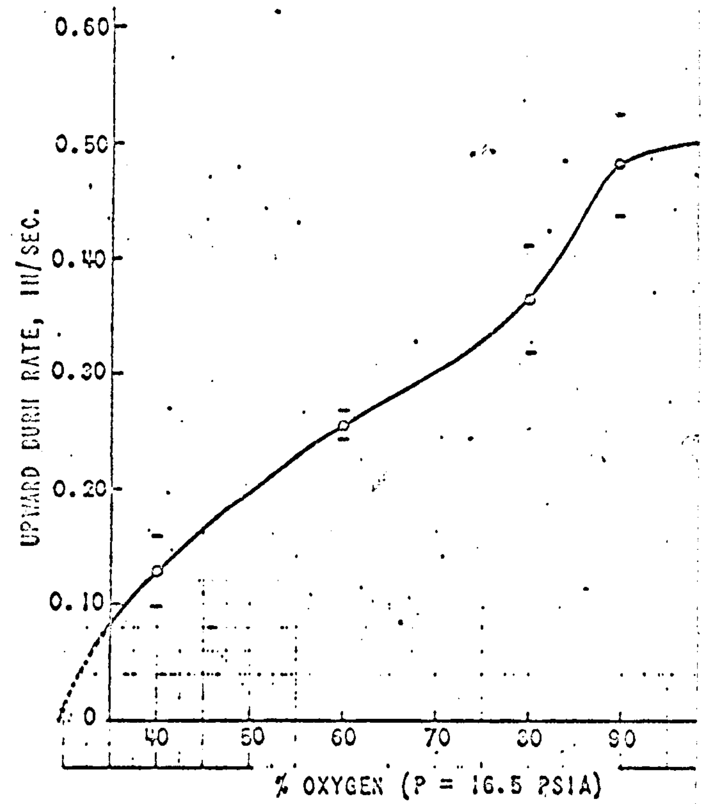
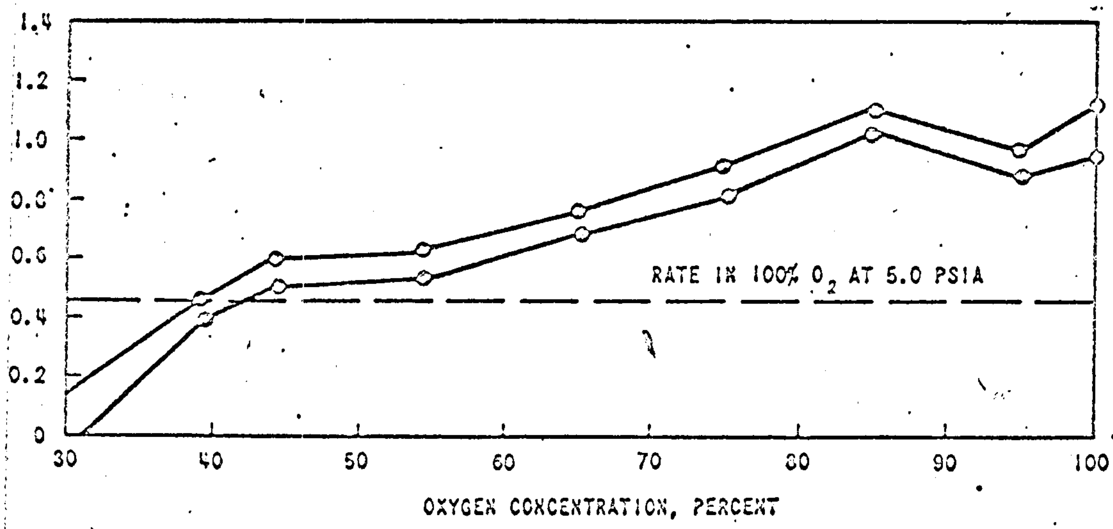


FIGURE - UPWARD PROPAGATION OF 0.005 INCH TEFLON IN VARIOUS O_2/N_2 MIXTURES AT A TOTAL PRESSURE OF 16.5 PSIA



SHEET 2 - UPWARD BURNING (9 & 17

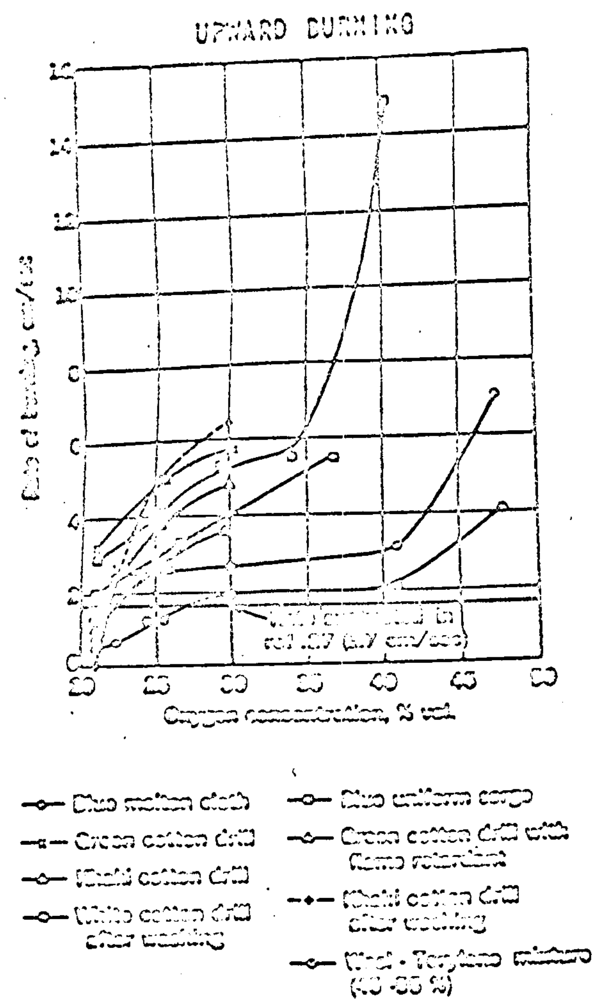


Figure 20.—Variation of burning rate with oxygen concentration. (After Coleman.)

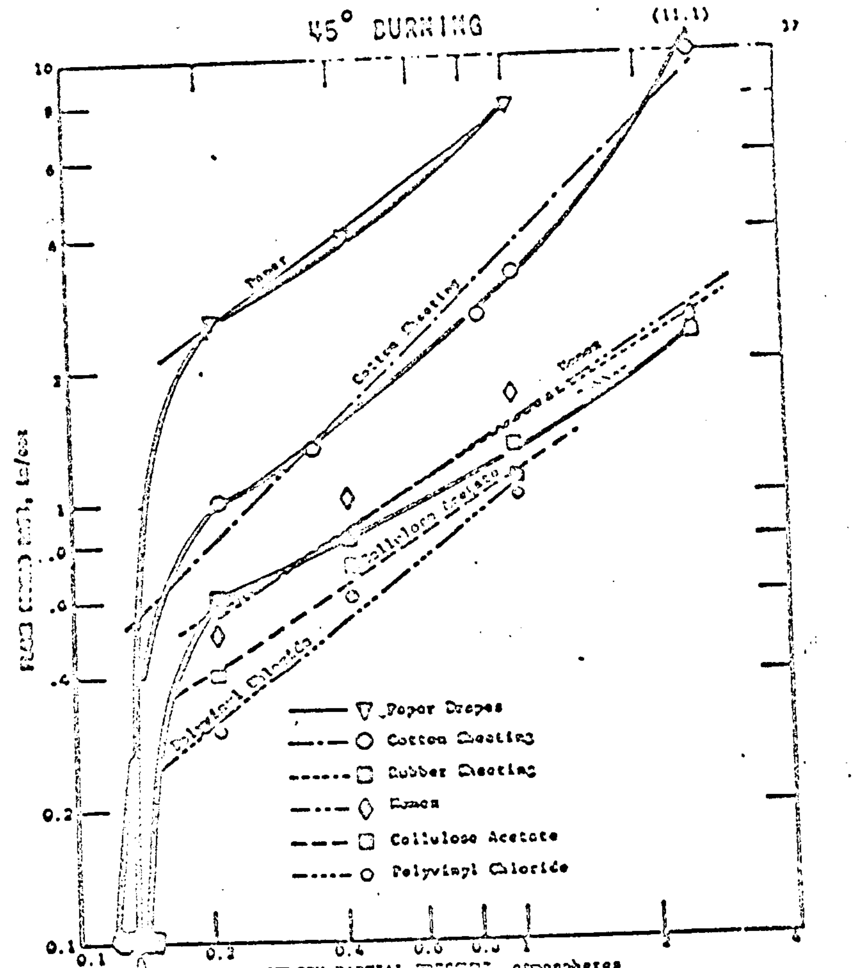


FIGURE 12. - Variation of flame spread rate with the partial pressure of oxygen for various materials in oxygen at 0.21 to 2.52 atmospheres total pressure.

PLUS POINTS OF ZERO FLAME SPREAD

SHEET 3 - BURNING OF A VARIETY OF MATERIALS IN O_2 ENRICHED ATMOSPHERES (1 & 8)

FLEXIPLE POWER LAW

$$R = F_A(O_{2MF})LOG\left[\frac{P^{F_m(O_{2MF})}}{(C_P)_{O_2} - N(C_P)_X}\right] + F_B(O_{2MF})$$

PROCESS SEQUENCE

- HEAT TRANSFER FROM IGNITION SOURCE TO FUEL
- PYROLYSIS
- HEATED GASES COMBINE IN EXOTHERMAL COMBUSTION
- HEAT TRANSFER TO IGNITE ADJACENT FUEL

EACH ESSENTIAL
FLAME PROPAGATION PROCESS

HEAT TRANSFER
PYROLYSIS
COMBUSTION

IS NON-LINEARLY SENSITIVE TO

- GASEOUS ENVIRONMENT
- TEMPERATURE

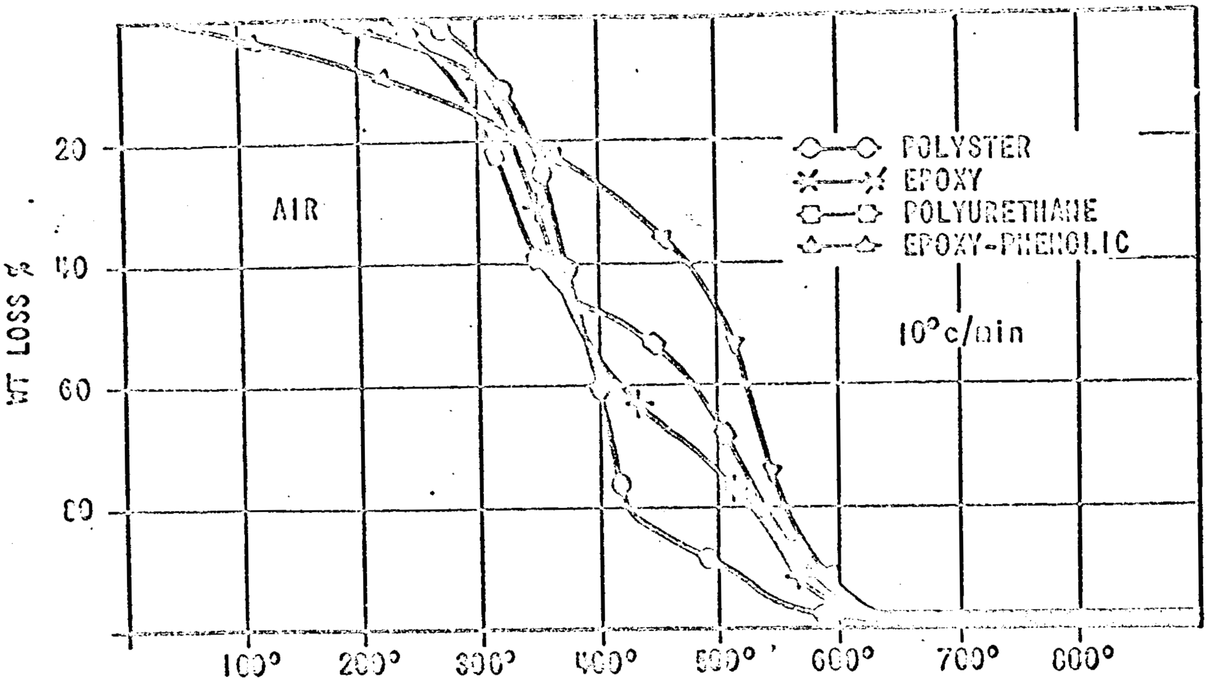


FIGURE 6 - PROGRAMMED THERMOGRAVIMETRIC CURVES (IN AIR)

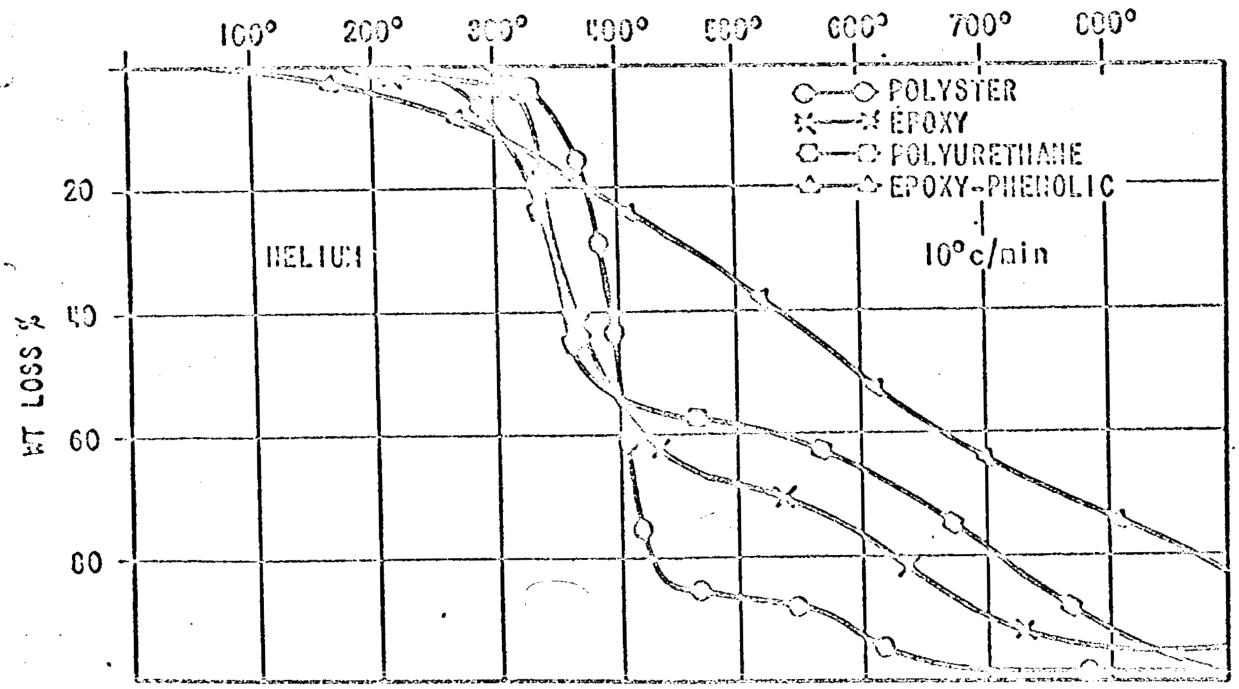
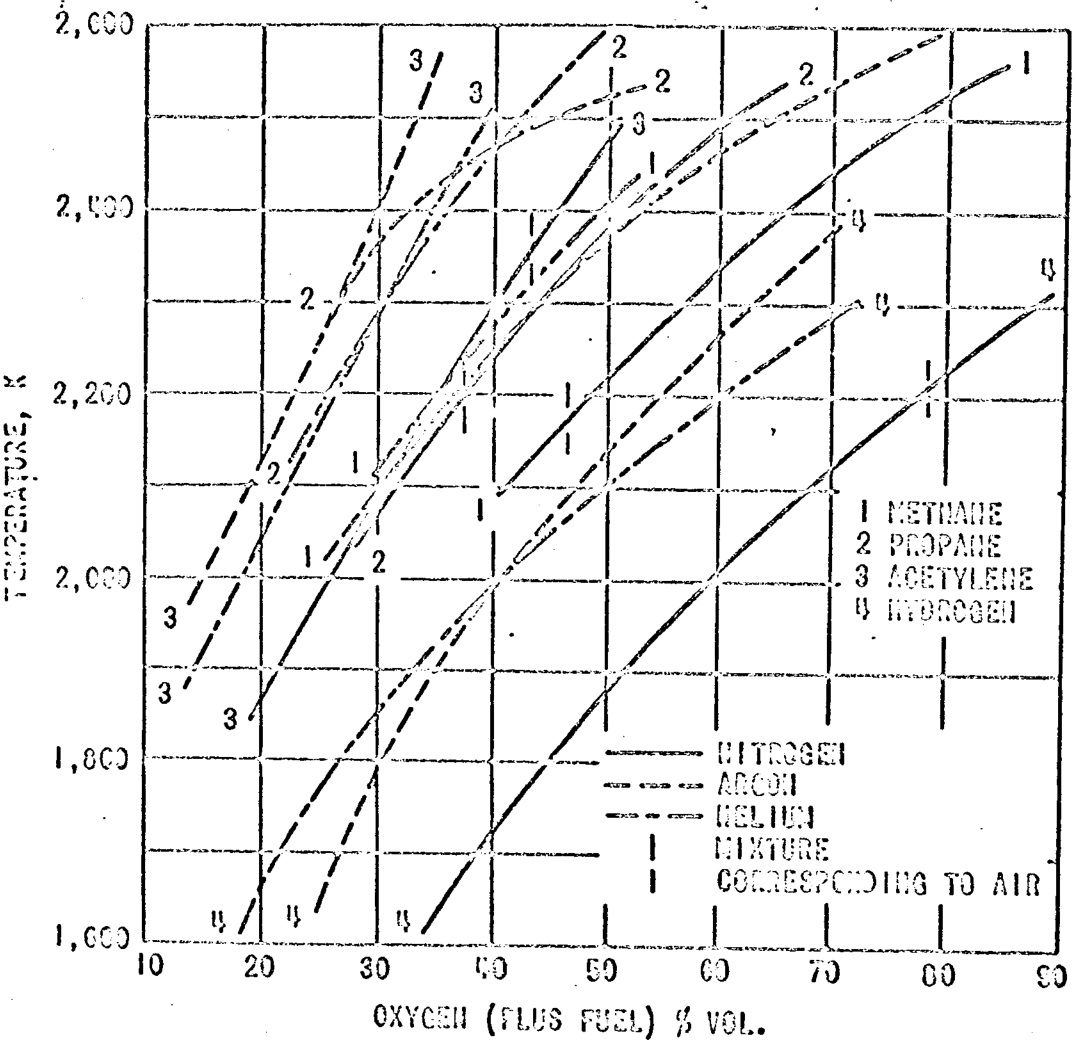


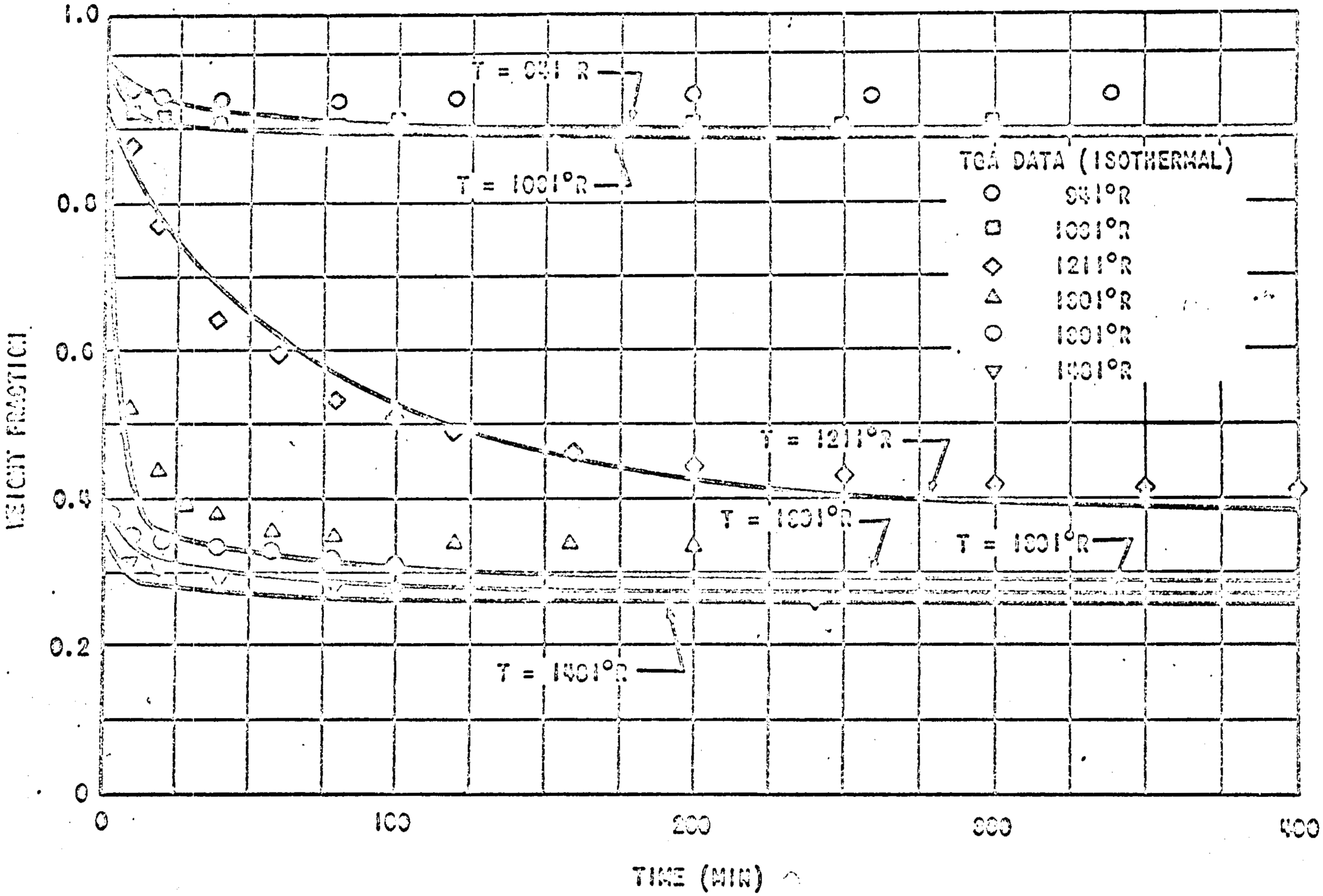
FIGURE 7 - PROGRAMMED THERMOGRAVIMETRIC CURVES (IN HELIUM)

SHEET 6 - TYPICAL TGA CURVES SHOWING NON-LINEAR RESPONSE[22]



SHEET 7 - FLAME TEMPERATURES IN VARIED INERT DILUENTS
(AFTER E. H. ROTH, CHAPTER 3 OF REF. 8)

FP-17



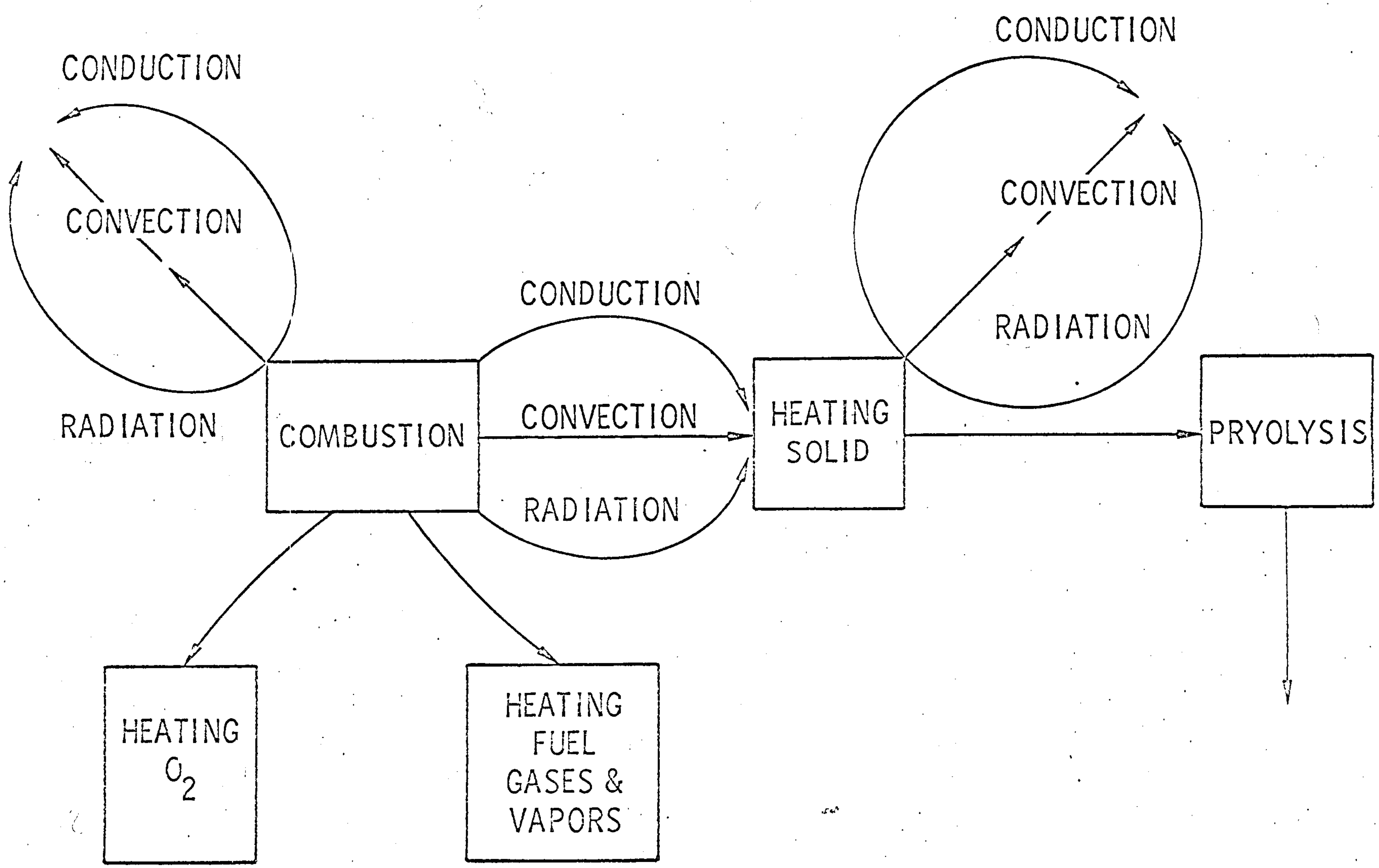
SHEET 8 - RATE OF PYROLYSIS AS FUNCTION OF TEMPERATURE[20]

LOGIC OF NON-LINEAR DEPENDENCE OF FLAME SPREAD UPON O_2 CONCENTRATION

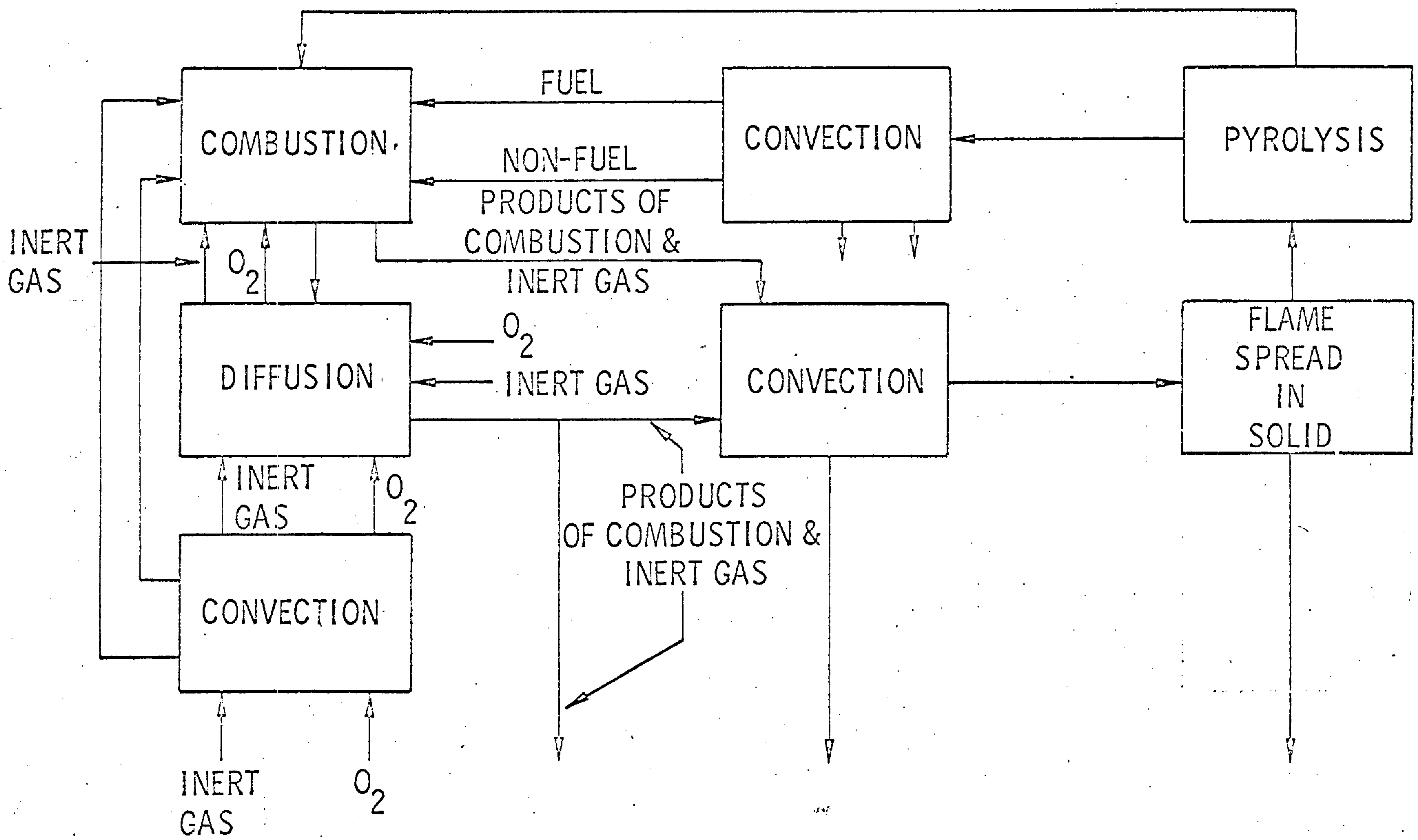
- PYROLYSIS UPON TEMPERATURE
  TEMPERATURE UPON O_2 CONCENTRATION
- TIME LAG IN PYROLYSIS IS FUNCTION OF TEMPERATURE

$$r = \frac{\dot{m}}{\rho A}^{P}$$

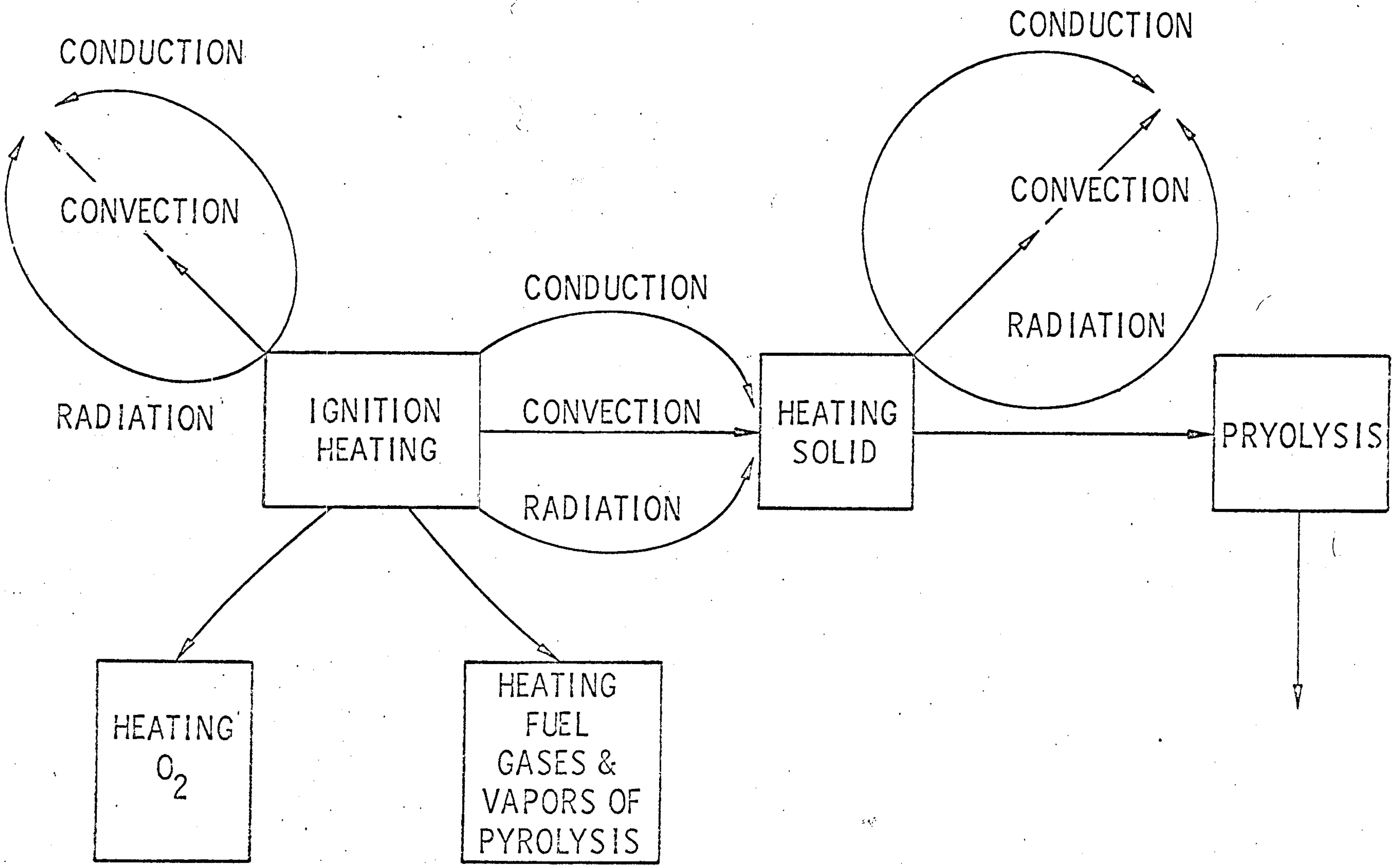
COMBUSTION ENERGY BALANCE



COMBUSTION MASS BALANCE



IGNITION ENERGY BALANCE



CONCLUSIONS

1. THE FLAME SPREAD VELOCITY INCREASES IN A DISTINCT, BUT HIGHLY NON-LINEAR (AND NON-POWER LAW) MANNER. AS MORE PRECISE EXPERIMENTAL DATA ARE GENERATED, THE RESPONSE MAY PROVE TO BE EVEN MORE COMPLEX THAN INDICATED BY THE LIMITED DATA NOW AVAILABLE.

2. TYPICALLY, THE FLAME VELOCITY INCREASES DRAMATICALLY AS OXYGEN CONTENT GOES UP JUST ABOVE THE POINT OF MINIMUM OXYGEN FOR SUPPORT OF COMBUSTION, AND THEN RISES SHARPLY AGAIN WITH HIGH OXYGEN CONCENTRATION.

3. IN ADDITION, BURNING DOWNWARD AND BURNING UPWARD DIFFER IN THAT THE DOWNWARD FLAME VELOCITY CONTINUES TO INCREASE UP TO 100% OXYGEN, WHILE UPWARD FLAME VELOCITY SEEMS TO LEVEL OFF JUST BELOW 100%.

4. THE NON-LINEAR DEPENDENCE OF PYROLYSIS ON OXYGEN CONCENTRATION AND THE HEAT TRANSFER DEPENDENCE ON FLAME TEMPERATURE MAY, WITH PROPER ANALYSIS, BECOME THE PHYSICAL BASES FOR A RATIONAL MODEL.

BELLCOMM, INC.

Subject: Briefing to OART on Our Activity in Combustion Analysis - Case 320

From: M. V. Drickman

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