DIESEL ENGINE COLD START
TRANSIENT COMBUSTION AND WHITE SMOKE

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CRITICAL TECHNOLOGIES FOR MODELING & SIMULATION OF GROUND VEHICLES

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OUTLINE

- Goal
- Cold Start Transients
- Visualization of Spray Autoignition for Model Development
- A Model for Spray Autoignition During Cold Starting
- Model and Experimental Results
- Application of Model Results to Improve Cold Starting
- Future Work

GOAL

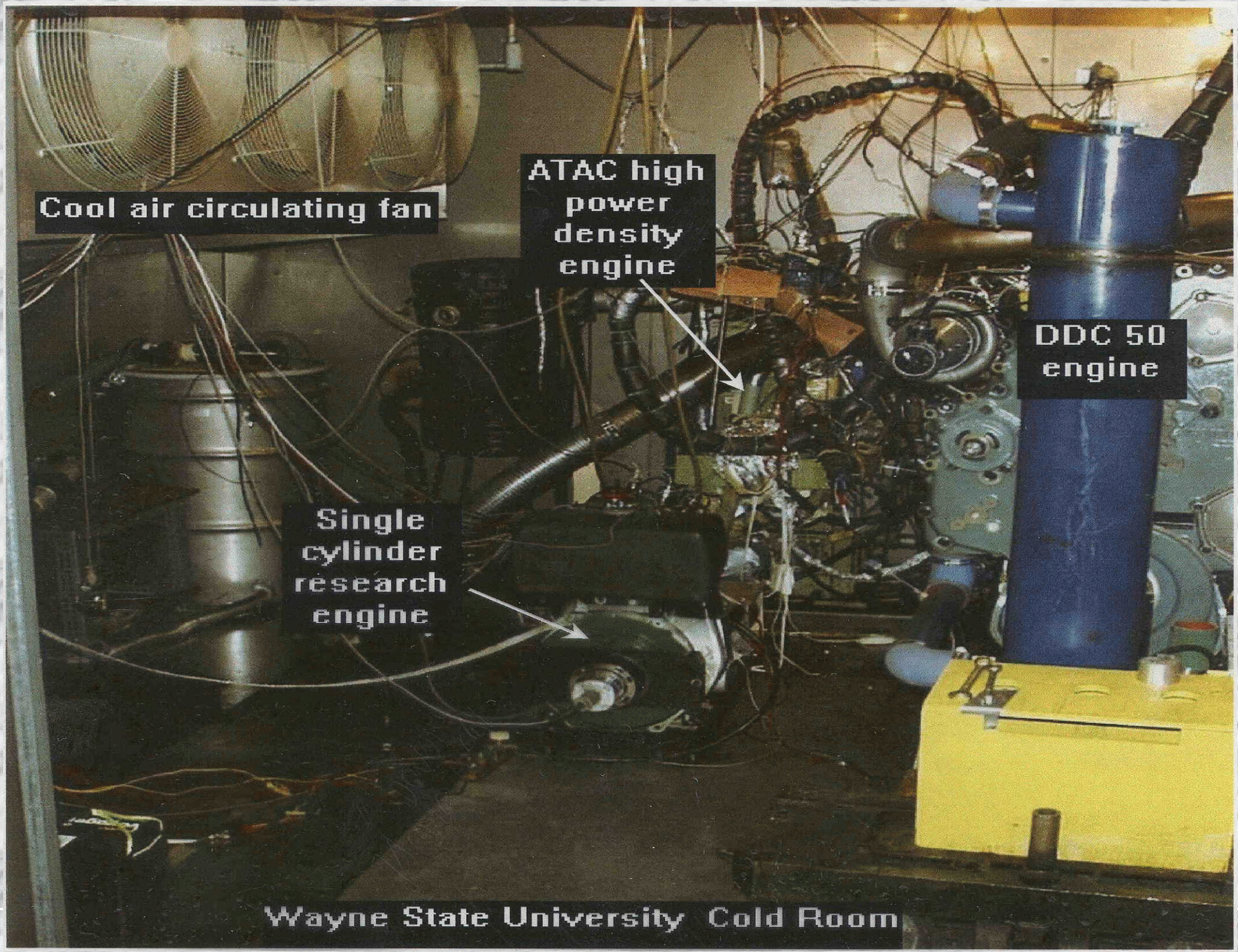
Military Applications:

- Prompt & reliable starting at low ambient temperatures, using DF2 & JP8
- Reduce visual signature in the field
- Reduce the environmental health hazard

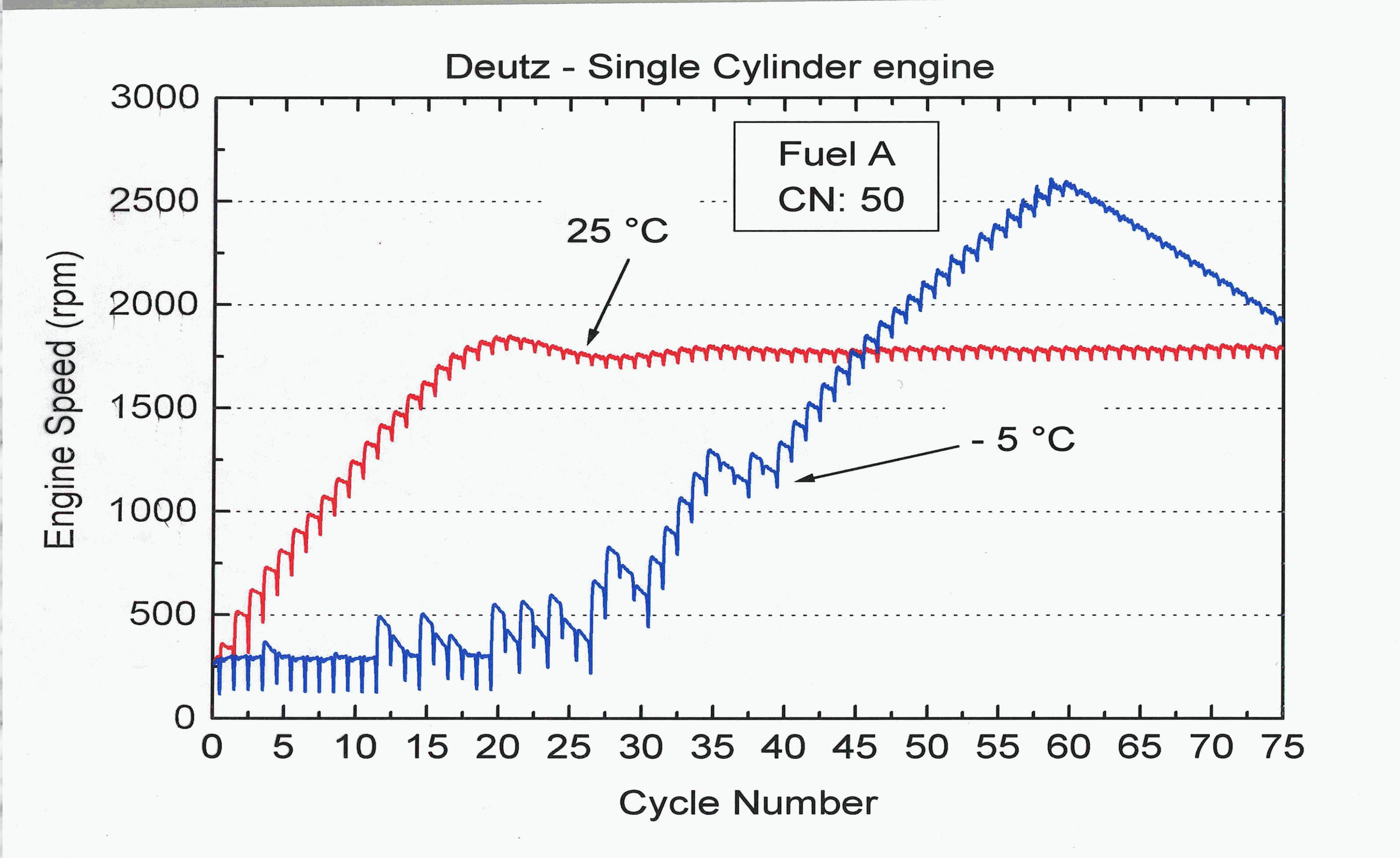
Domestic Applications:

- Reduce cold start HC & PM emissions

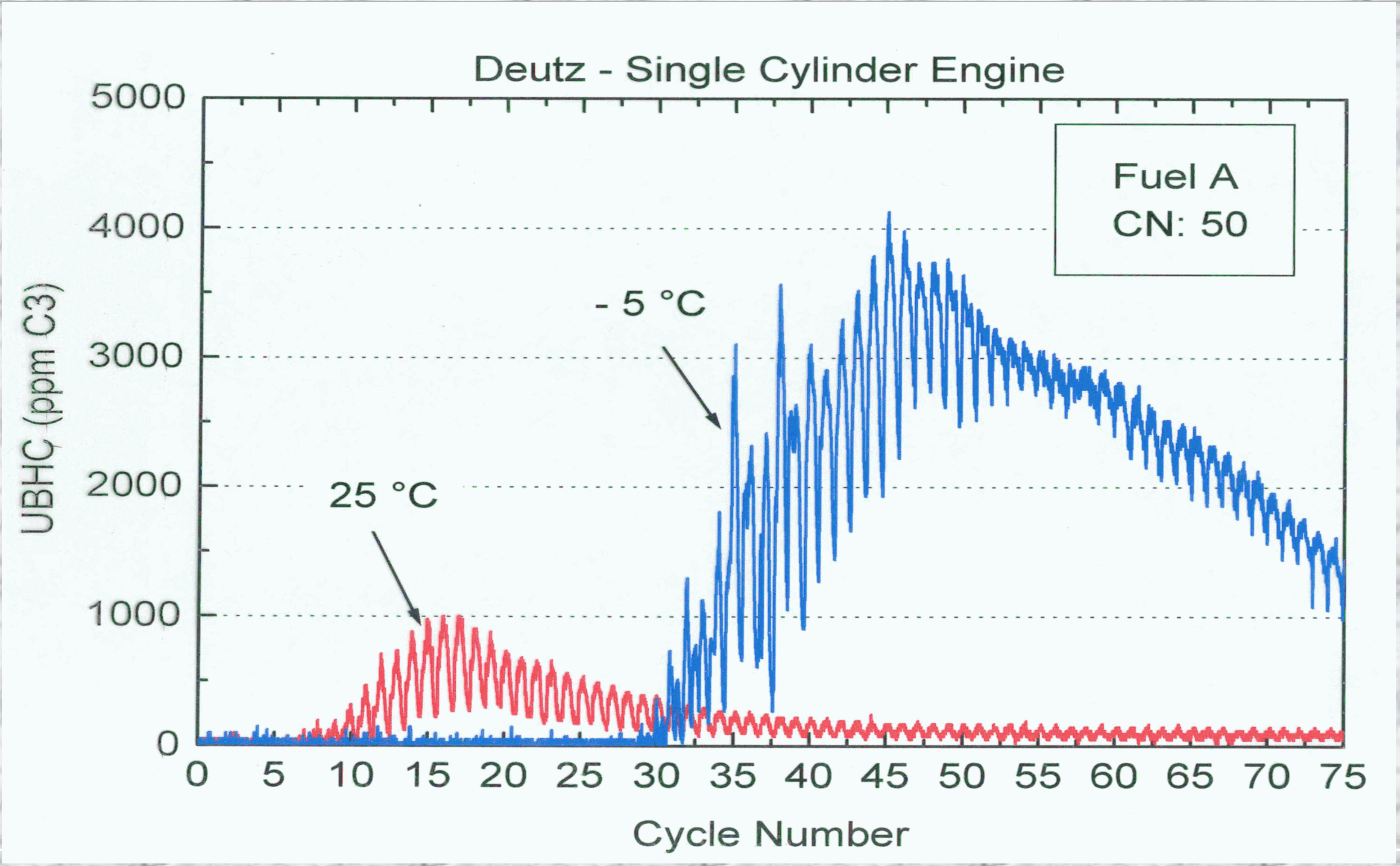
Photograph of The Cold Room



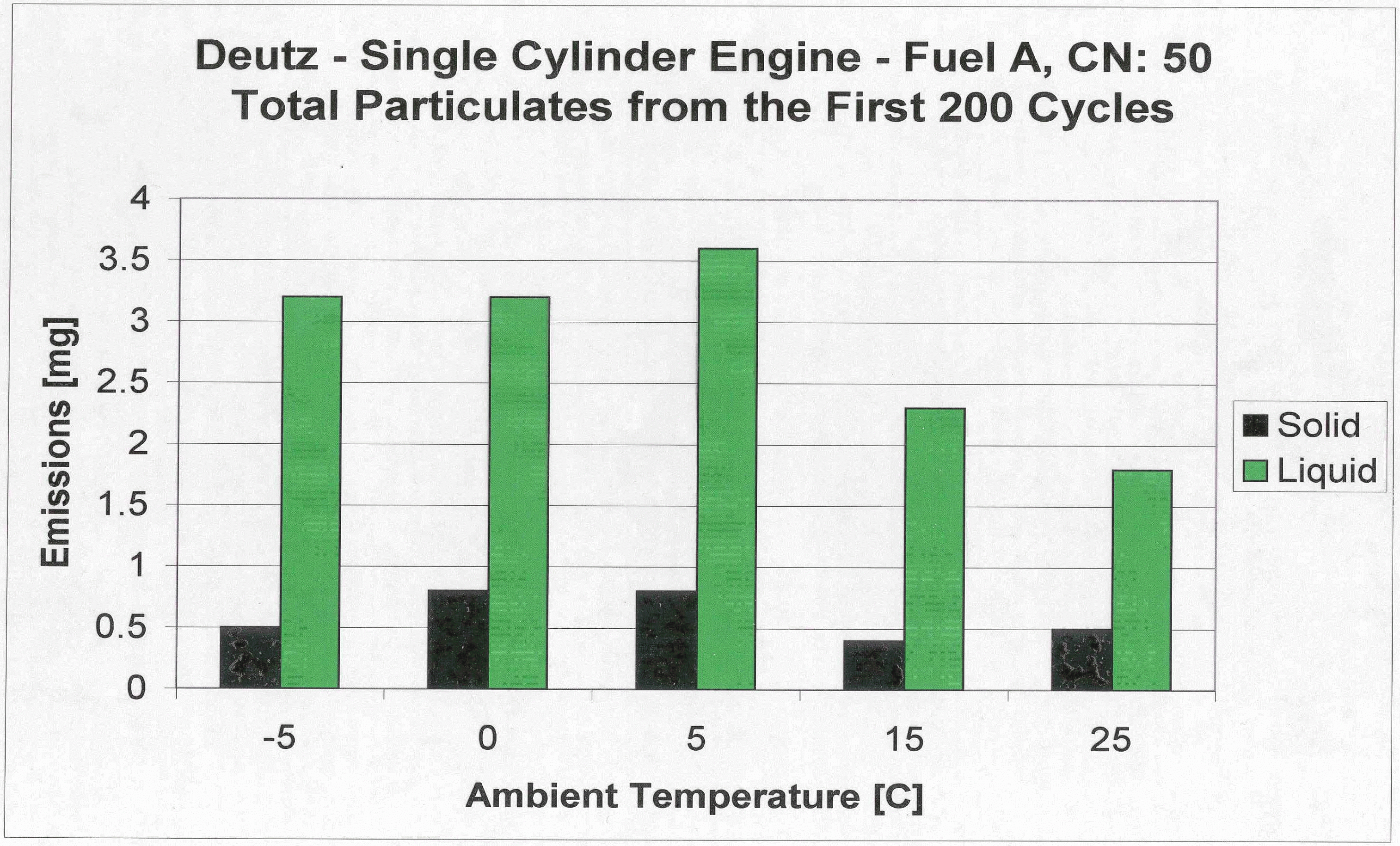
Cold Start Transients: Deutz - Single-Cylinder Engine



EFFECT of COMBUSTION INSTABILITY ON HC EMISSIONS



EFFECT OF COMBUSTION INSTABILITY ON SOLID AND LIQUID PARTICULATES



Cold Start Transients: Single-Cylinder Engines

Combustion instability has been detected in the three single cylinder engines we tested.

- Stand-alone engine:

  4-stroke -cycle, air cooled, DI, d:95mm, l:95mm, CR:17

- High-power density TACOM engine:

  4-stroke-cycle, water cooled, DI, d:114.3mm, l:114.3mm, CR: 16.5

- Optically accessible engine:

  4-stroke-cycle, extended piston, DI, d:120mm, l:120mm, CR:16.5

Is combustion instability specific, only to single cylinder engines?

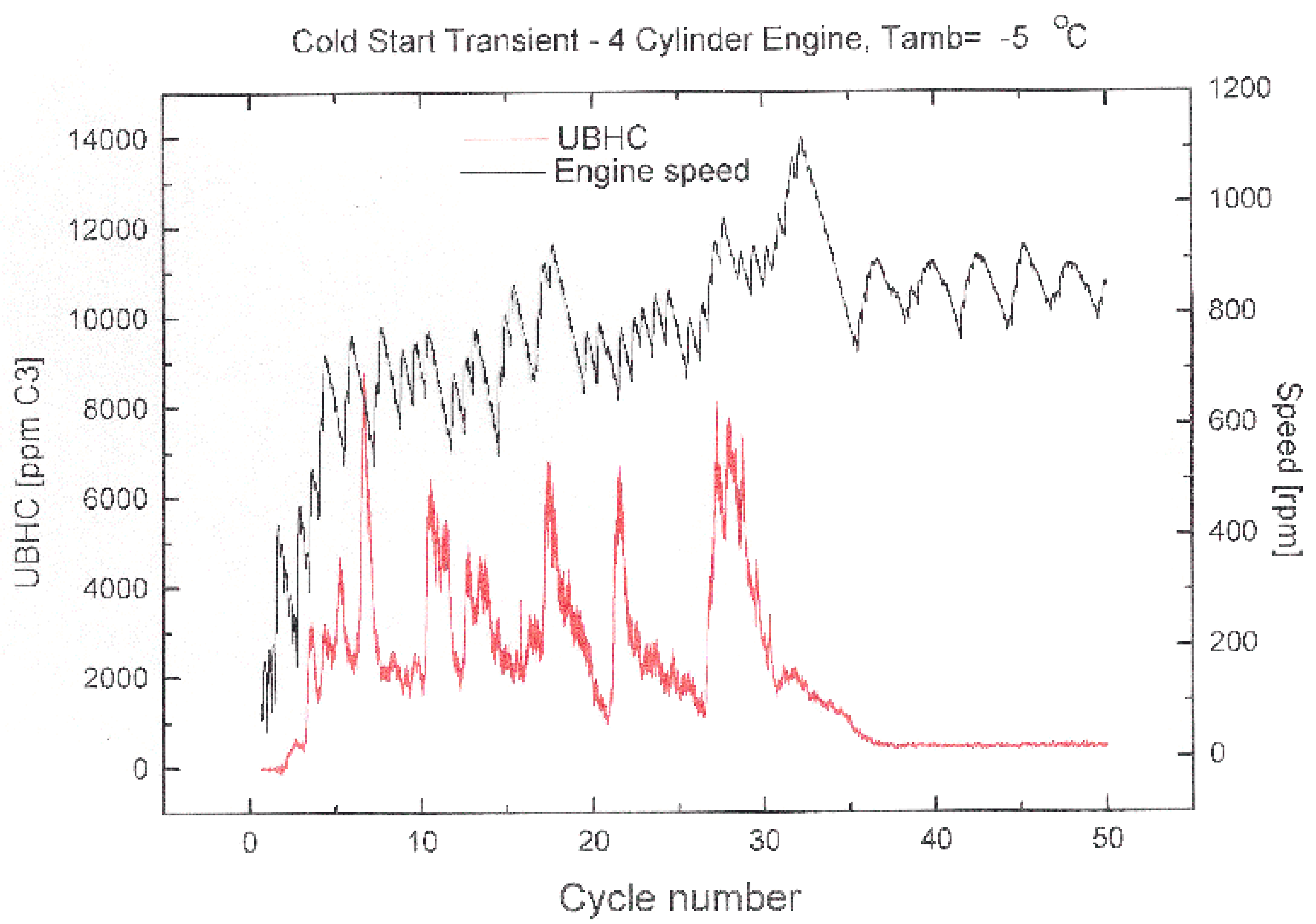
COLD START TRANSIENTS: MULTI-CYLINDER ENGINES

Combustion instability has been observed in the following two heavy-duty, 4-stroke-cycle, DI engines:

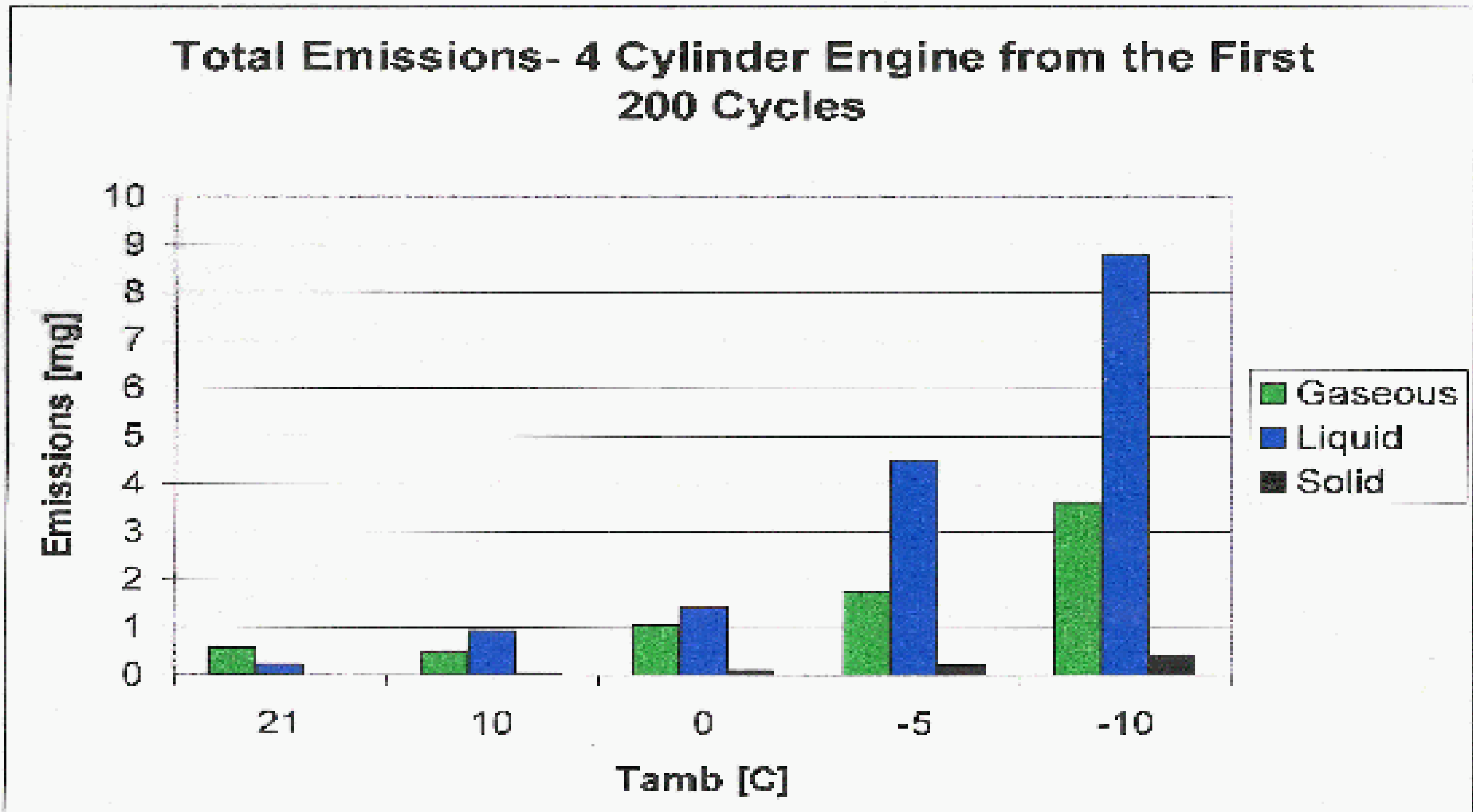
- Turbo-charged
- Inter-cooled
- Four-cylinder and six-cylinder
- Water cooled
- Of different makes
- Tested using DF-2 and JP8

COLD START TRANSIENTS:
4- CYLINDER ENGINE

- Engine Speed Transient and Corresponding HC and Solid and Liquid Particulates.
- With DF-2
- Is Combustion Instability Specific for DF-2?


Cold Start Transient - 4 Cylinder Engine, Tamb= -5 °C
UBHC
Engine speed
UBHC [ppm C3]
Speed [rpm]
Cycle number
14000
12000
10000
8000
6000
4000
2000
0
1200
1000
800
600
400
200
0
0
10
20
30
40
50

TOTAL MASS EMITTED AFTER THE FIRST 200 CYCLES



FUELS TESTED IN SINGLE- & MULTI-CYLINDER ENGINES

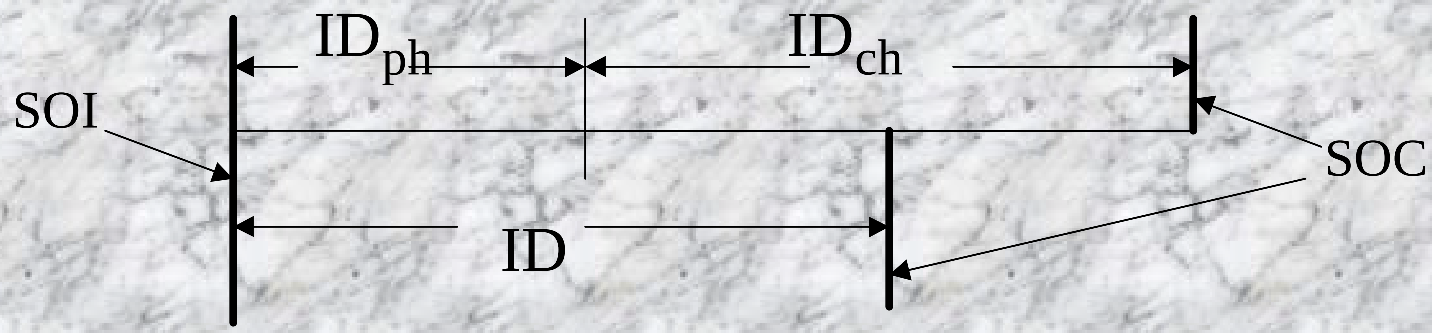
Fuel	Density	CN	T_{10} °C
DF-2	0.8547	45	209
JP-8	0.79	37	168
Ref-1	0.78	27.8	110
Ref-2	0.923	30	258
Special Fuels	0.8066	30.8	170.0
	0.8346	49.2	175.5

All these fuels produced unstable combustion.

NEW CONCEPTS in MODELING AUTOIGNITION REACTIONS

The models are based on two new concepts:

1. The autoignition reactions proceed in parallel with the physical processes.



2. Autoignition occurs in a heterogeneous mixture of fuel and air.

CAUSE OF MISFIRING AFTER FIRING

- Imbalance between engine dynamics and the autoignition reactions kinetics.
- The dynamics factor has been explained in

  “ Fundamental Cold Start Phenomena Within Advanced Military Diesel Engines,” W. Bryzik, and N. A. Henein, Army Science Conference Proceedings, Vol.III, pp1091-1099, 1994.

- The chemical kinetics factor, considering global reaction rates, was presented in ARC 1998 Conference and published: *“ Diesel Ignition Model Considering Charge Heterogeneity and Global Reaction Rates,” Y. Itoh, N. A. Henein and W. Bryzik, The Fourth International Symposium COMODIA 98, Japan. pp129-133, 1998.*

LIMITATIONS OF THE GLOBAL MODEL

1. It is based on empirical correlations derived from experiments on constant volume vessels.

2. It does not account for the chemical effects of the residual combustion products (left over from the previous firing cycle) on the autoignition reactions

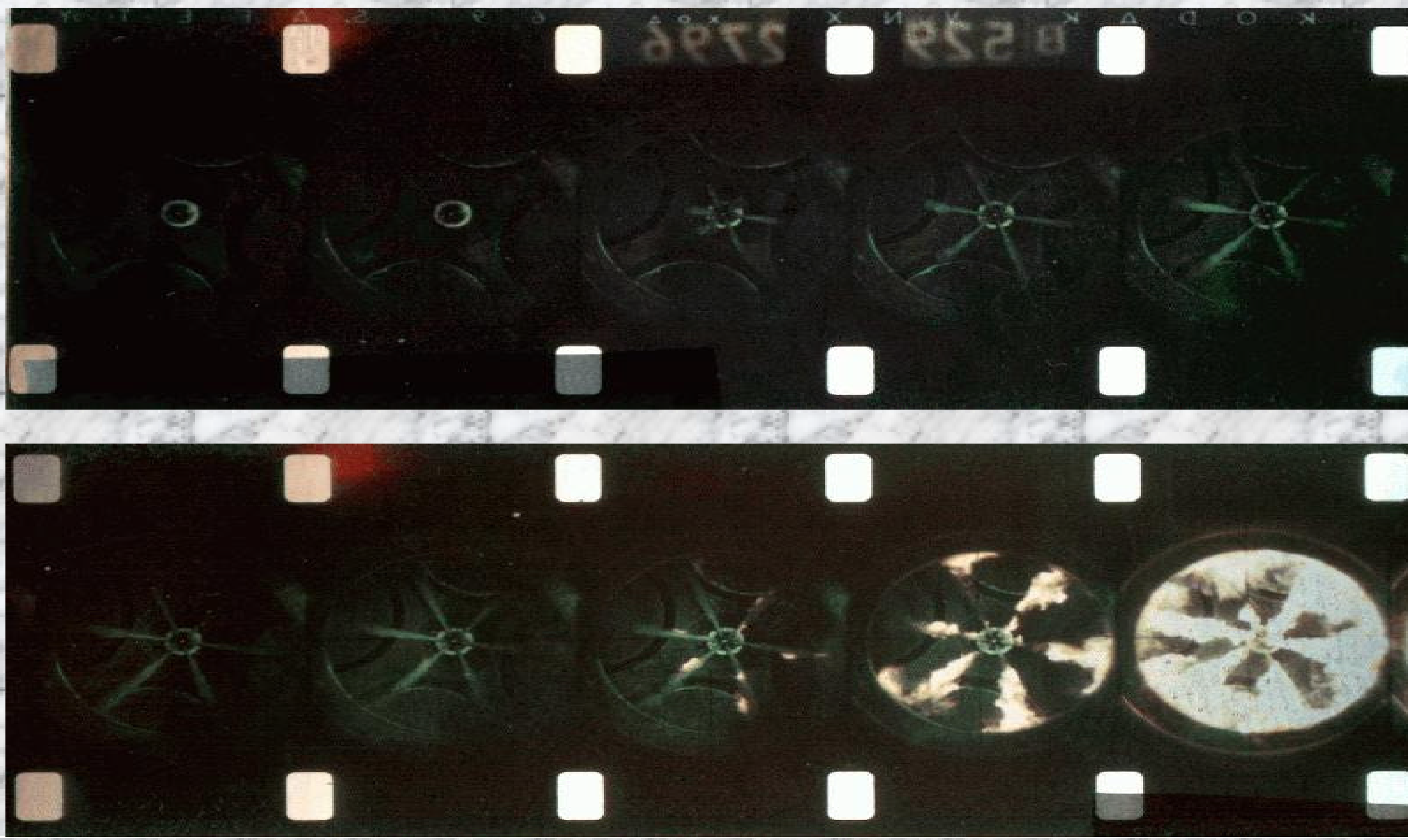
3. It cannot estimate cold start emissions such as HCs and aldehydes.

AUTO-IGNITION VISUALIZATION for MODEL DEVELOPMENT

- Engine:
  - AVL 520, optically accessible
  - Speed: 700 rpm
- Injection System:
  - HEUI , 38 MPa, 10°BTDC, VCO tip
- Intake air:
  - Pin.= 1.55 bar, Tin = 75 °C

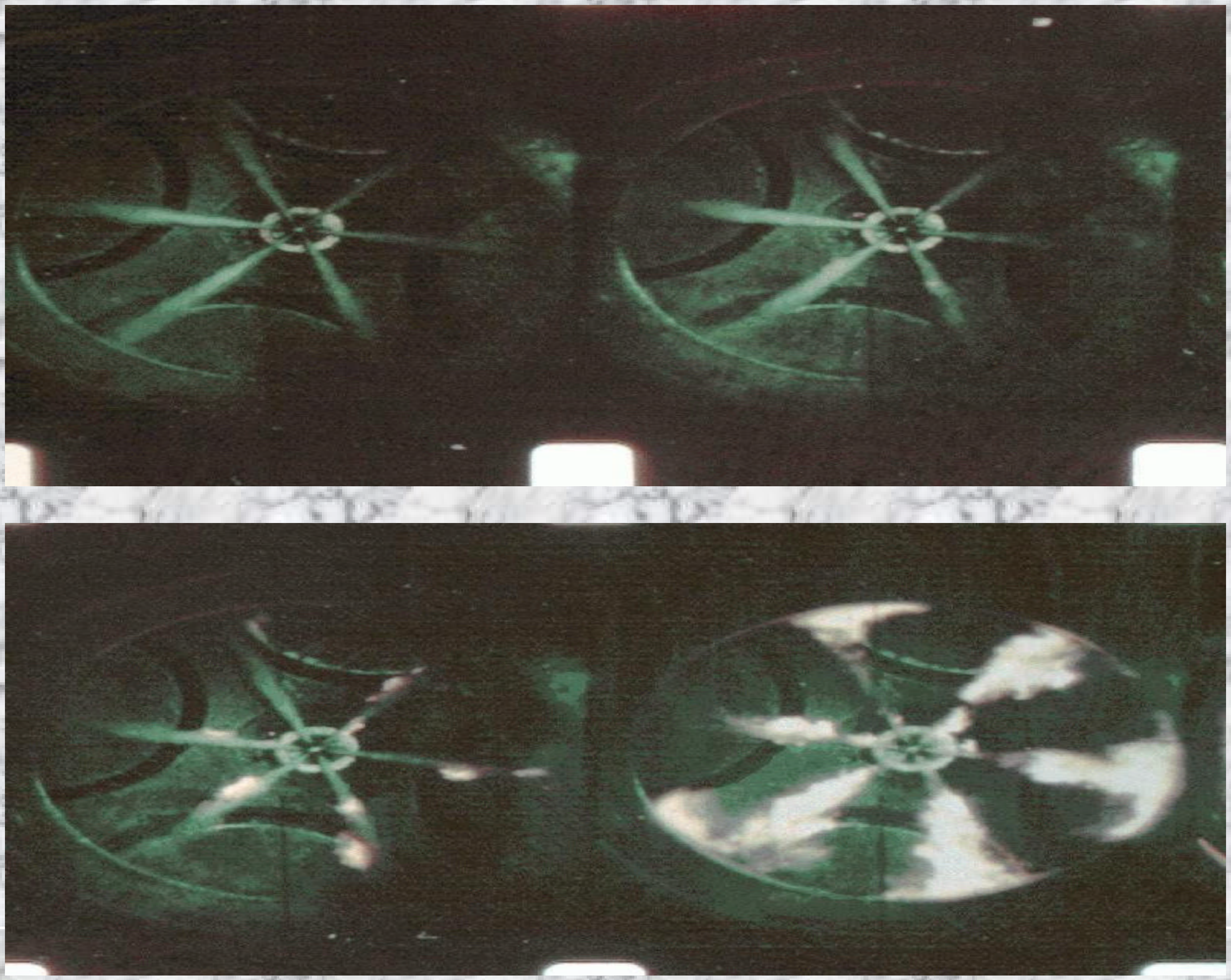
DIESEL AUTOIGNITION VISUALIZATION (6 frames)

Optically accessible engine: d = 120 mm, L = 120 mm, C.R. = 16.5, 700 RPM



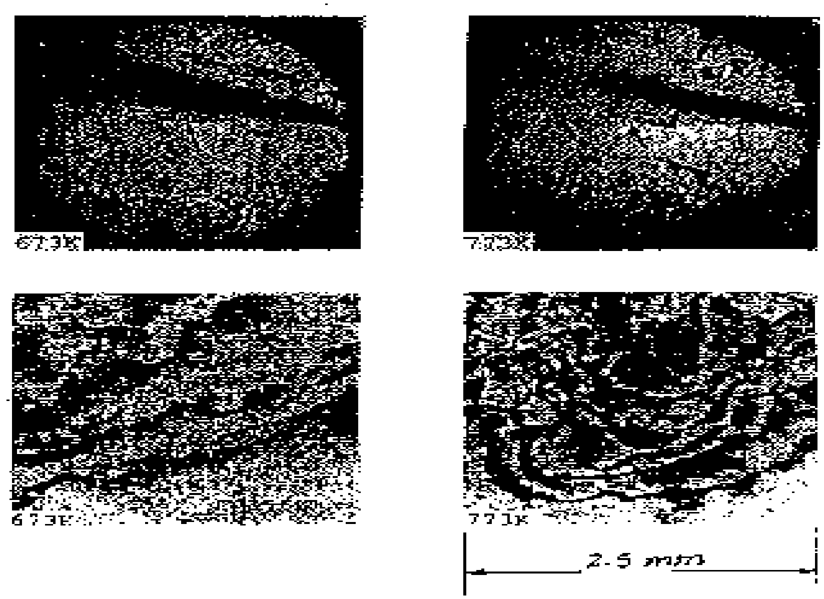
VISUALIZATION OF SPRAY FORMATION & AUTOIGNITION

Optically accessible engine: d = 120 mm, L = 120 mm, C.R. = 16.5, 700 RPM



STRUCTURE OF DIESEL SPRAYS : Nishida et al. 1985

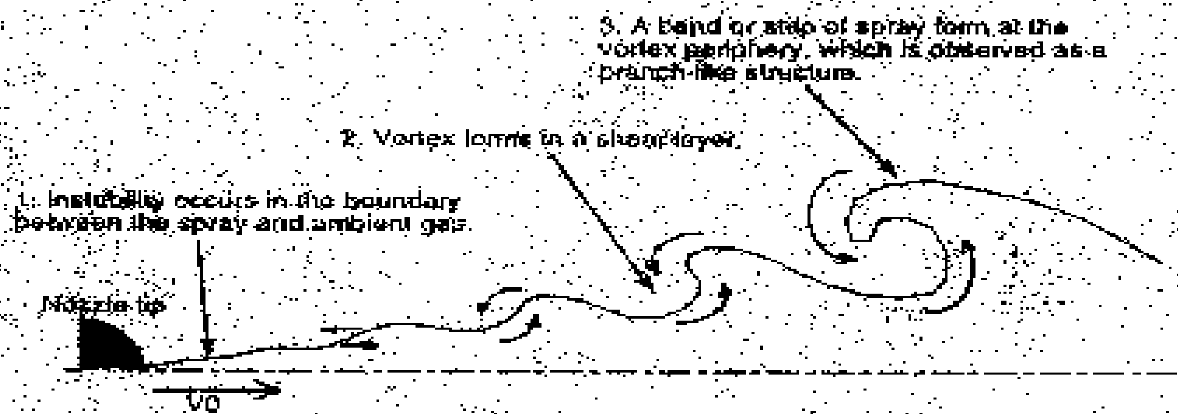
STRUCTURE OF DIESEL SPRAYS
(Nishida, K., Murakami, N. and Hiroyasu, H., Tran. JSME,1985)



Interference fringes observed using Double-Pulsed Ruby Laser Holography.

STRUCTURE OF DIESEL SPRAYS : ISHIKAWA et al 1996

STRUCTURE OF DIESEL SPRAYS
(Ishikawa, N. and Niimura, K., SAE 960770)



Schematic of Branch-like Structure Formation Process

PROPERTIES OF THE VORTICES IN THE SPRAY PERIPHERY

- The size, number density, and droplet size in the eddy depend on:

  1. Injection pressure which affects

     (a) relative velocity between the spray and air,

     (b) atomization

  2. Swirl motion which controls the down wind spread of the spray

EFFECT OF EQUIVALENCE RATIO

- The vortices formed in the spray periphery are heterogeneous, but have an ensemble average equivalence ratio that depends, mainly, on injection pressure and swirl.
- What is the effect of the ensemble average eddy equivalence ratio on the autoignition reactions?

EFFECT OF EQUIVALENCE RATIO ON AUTOIGNITION REACTIONS

$$d[i]/dt = k_0 \exp(-E/RT)[F][O_2]$$

- At high equivalence ratios, the heat transfer from the air to the droplets reduces the local temperatures of the mixture.
- However, richer mixtures have higher concentrations of fuel vapor which increase the rate of reaction.

AUTOIGNITION REACTIONS MODEL

- The mechanism developed by Sahetchian et al[1] consists of 32 reactions and 18 species for the autoignition of heavy fuels, such as n-dodecane, in a constant volume vessel.
- The emphasis is on the low temperature oxidation reactions.
- Autoignition is considered to occur when the temperature of the site reaches 900K
- *(1) Sahetchian, K et al." Experimental Study and Modeling of Dodecane Ignition in a Diesel Engine," Combust. Flame 103:207-220(1995).*

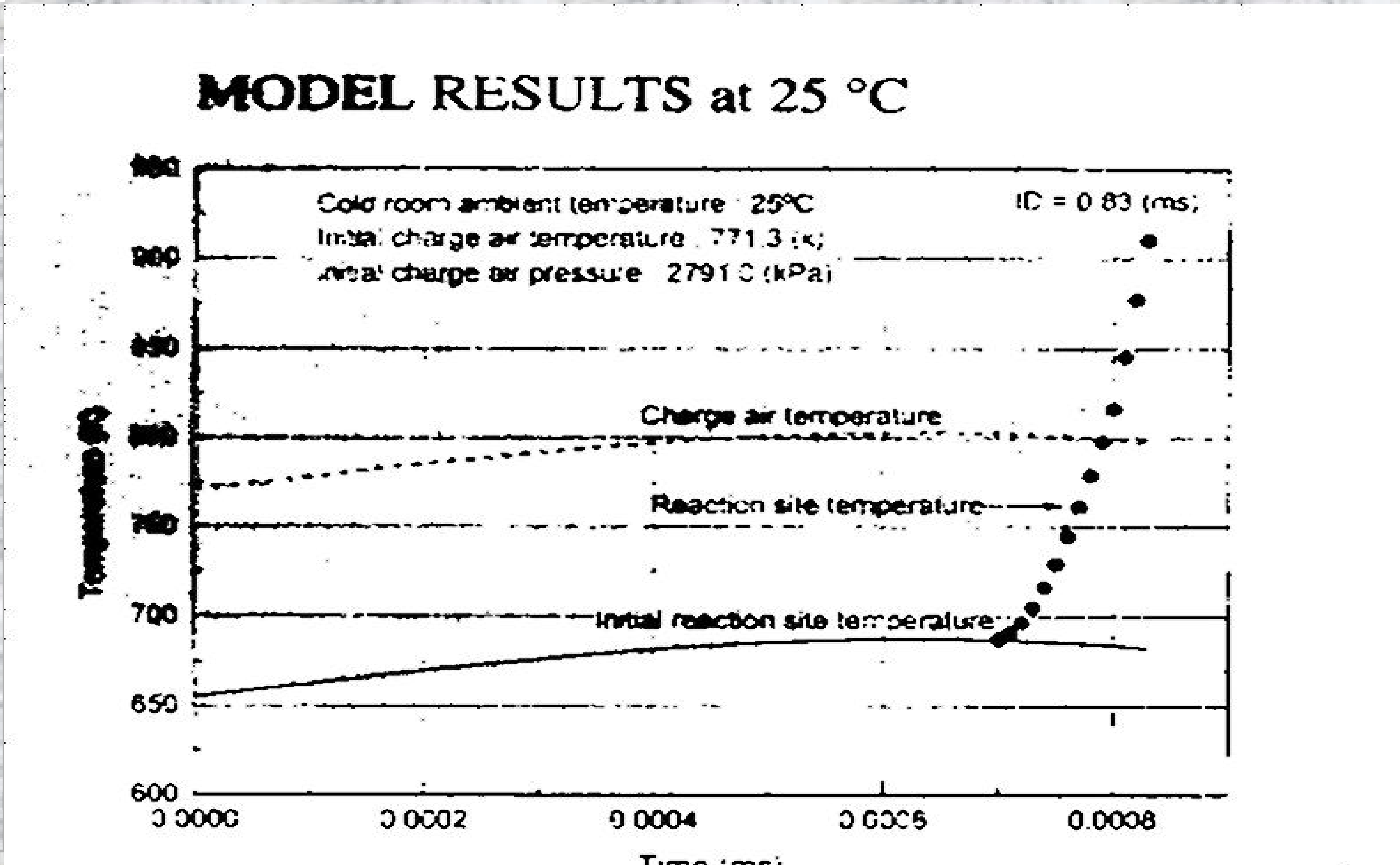
MODEL DEVELOPMENT FOR DIESEL ENGINES

- The development is planned in two stages:
  1. Apply the detailed reaction mechanism under engine conditions without considering the chemical effect of residual products of the precious firing cycle.
  2. Include the effect of charge dilution.

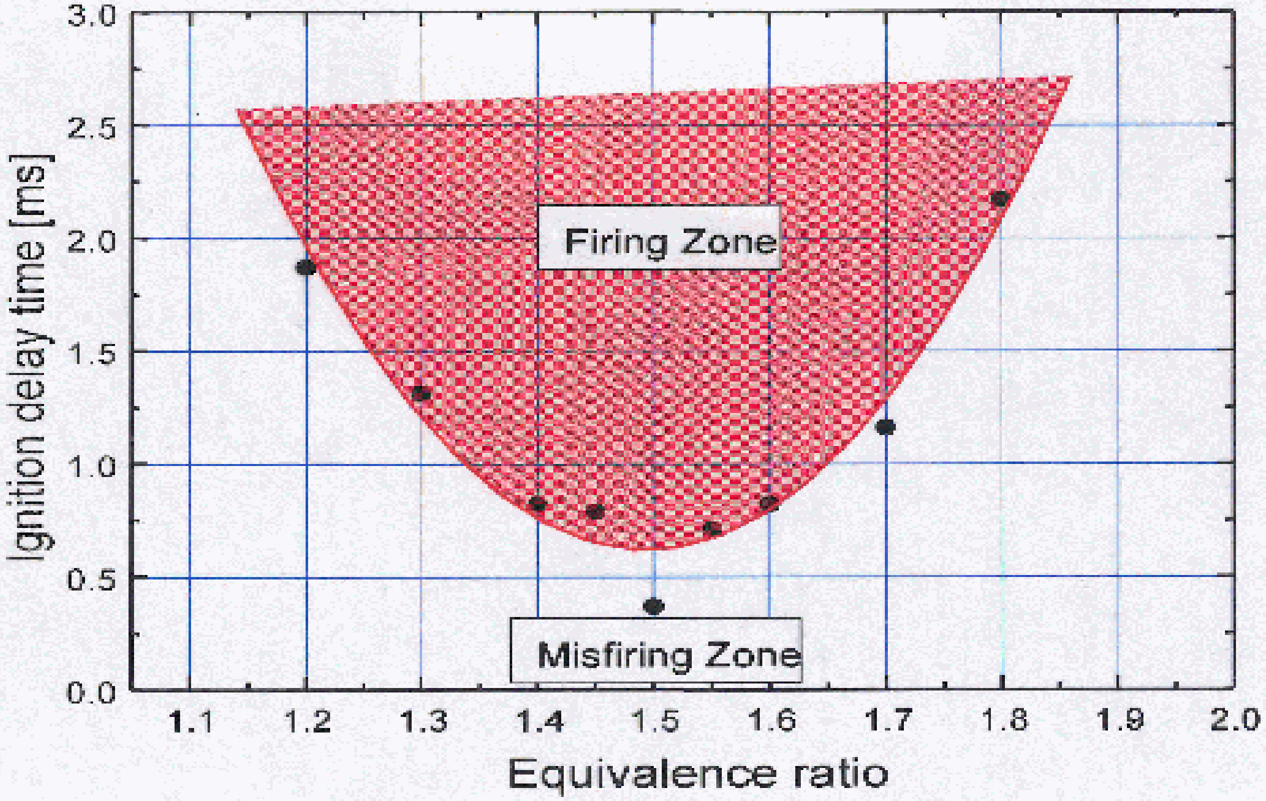
PROCEDURE

- Calculate the initial reaction site temperature at different equivalence ratios.
- Calculate the change in the concentration of 18 species and the corresponding change in the site temperature, considering successive elements.
- The changes in pressure and temperature during ID are considered.
- Autoignition occurs when the reaction site temperature reaches 900K.

MODEL RESULTS at 25 °C

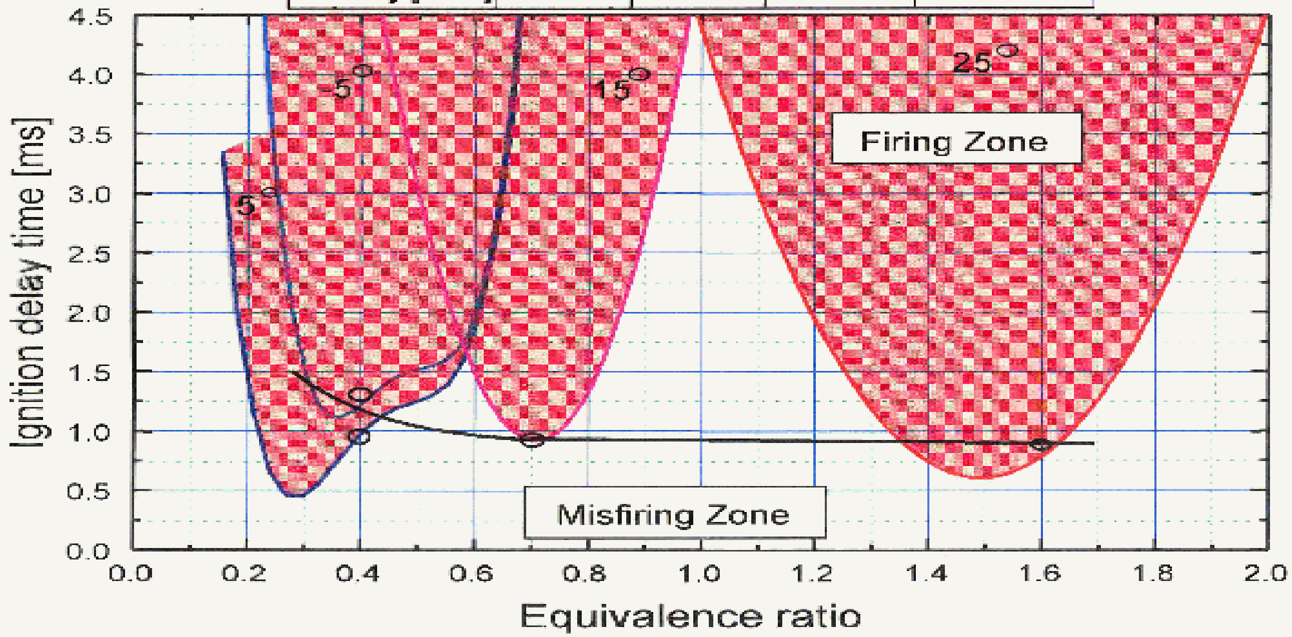


MODEL PREDICTION OF FIRING AND MISFIRING ZONES



MISFIRING ZONES AT DIFFERENT AMBIENT TEMPERATURES

Tam [C]	25	15	5	-5
Tinj [K]	771.3	708.8	686.9	679.8
Pinj [kPa]	2791.0	2705.0	2757.2	2620.1



APPLICATION OF MODEL RESULTS

The model results suggest the following to improve combustion during cold starting:

1. Increase the injection pressure to improve atomization.

2. Increase air swirl to spread the spray in the down wind direction.

- This can be easily achieved in advanced Injection systems

PLANS FOR FUTURE WORK

- Include the effect of charge dilution with residual combustion products in the model.
- Verify the model results on the single cylinder diesel engine at different cold room temperatures.
- Verify the model results on a heavy duty diesel engine.

ACKNOWLEDGEMENT

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