THERMODYNAMIC ADVANTAGES OF LOW TEMPERATURE COMBUSTION (LTC) ENGINES INCLUDING THE USE OF LOW HEAT REJECTION (LHR) CONCEPTS

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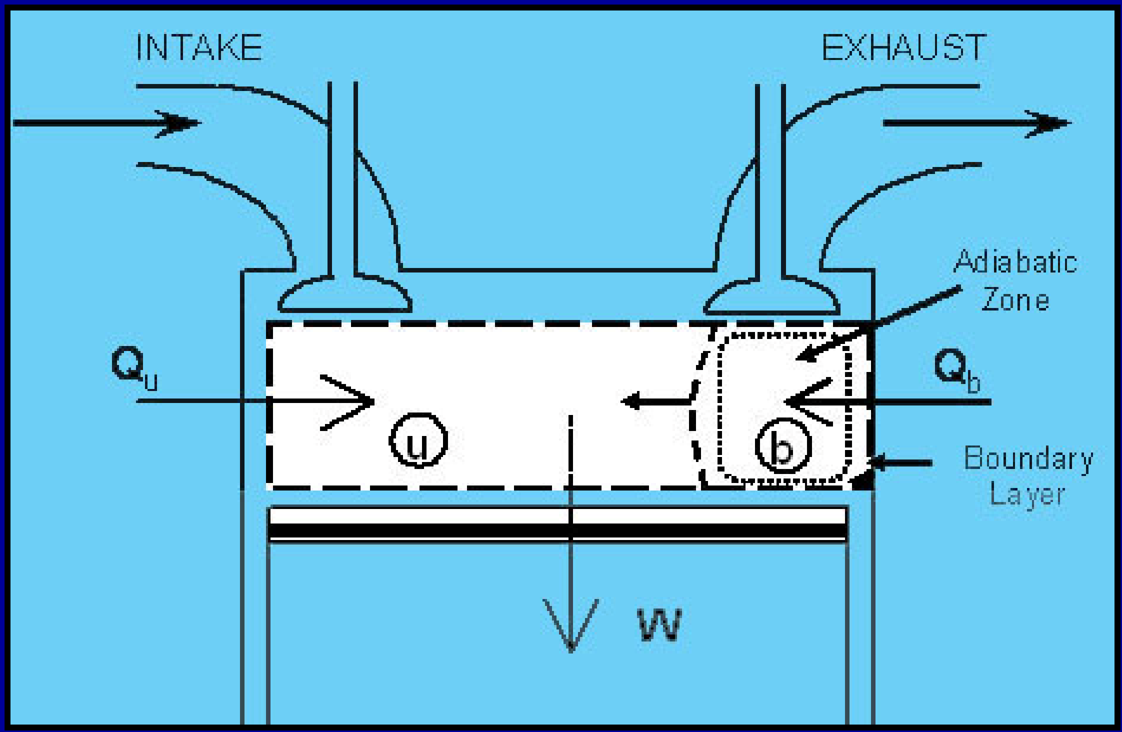
THERMODYNAMIC ADVANTAGES OF LOW TEMPERATURE COMBUSTION (LTC) ENGINES INCLUDING THE USE OF LOW HEAT REJECTION (LHR) CONCEPTS

- INTRODUCTION AND BACKGROUND
- DESCRIPTION OF THE CYCLE SIMULATION
- RESULTS AND DISCUSSION
  - ✓Engine and Operating Conditions
  - ✓Overall Results – Efficiencies
  - ✓Parametric Evaluations
  - ✓Nitric Oxide Results
- SUMMARY AND CONCLUSIONS

INTRODUCTION AND BACKGROUND

- LTC engines have demonstrated low emissions and high efficiencies
- These engines use combinations of high CR, high EGR, lean mixtures, fast burn rates, high boost and other features
- What is the contribution to the high efficiencies by each of these features?
- What are the best combinations of these features?
- Does including LHR concepts make sense? Why or why not?
- What does the second law say?
- What is the impact on nitric oxide emissions?

THERMODYNAMIC ENGINE CYCLE SIMULATION



Features/Considerations:

1. One common pressure
2. Three gas temperatures
3. Three volumes and masses
4. Separate heat transfer

PROCEDURES FOR SOLUTIONS

- ORDINARY DIFFERENTIAL EQUATIONS
- NUMERICAL TECHNIQUES: EULERS
- INITIAL CONDITIONS: T_1, p_1, Residual Fraction
- BOUNDARY CONDITIONS: INLET & EXHAUST
- SPECIFY SUBMODEL PARAMETERS:
  - Thermodynamic properties
  - Heat transfer coefficient
  - Fuel mass rates
  - Flow rate parameters
  - Nitric oxide kinetics
  - Other

SPECIFICATIONS FOR THE ENGINE

PARAMETER	VALUE
Engine	Automotive, V-8
Bore/Stroke	102/88 mm (4.0/3.5 in)
Displacement	5.7 liter (350 in^3)
bmep	900 kPa
Engine speed	2000 rpm
Combustion timing	MBT
Geometric compression ratio	from 8:1 to 20:1
Valve arrangement	OHV, 2 valves/cylinder

DESCRIPTION OF CASES

-- STRATEGY –

Add features in a sequential fashion:

CASE	DESCRIPTION
1	CR = 8; BD = 60°; φ= 1.0; EGR = 0%; T_w = 450 K
2	CR = 20; BD = 60°; φ= 1.0; EGR = 0%; T_w = 450 K
3	CR = 20; BD = 30°; φ= 1.0; EGR = 0%; T_w = 450 K
4	CR – 20; BD – 30°; φ– 0.7; EGR – 0%; T_w – 450 K
5	CR = 20; BD = 30°; φ= 0.7; EGR = 50%; T_w = 450 K
6	CR = 20; BD = 30°; φ= 0.7; EGR = 50%; T_w = 550 K

RESULTS

- Thermal Efficiencies
- Cylinder Conditions
- Heat Transfer/Exhaust Energy
- Parameter Optimization
- Nitric Oxides
- Low Heat Rejection (LHR)

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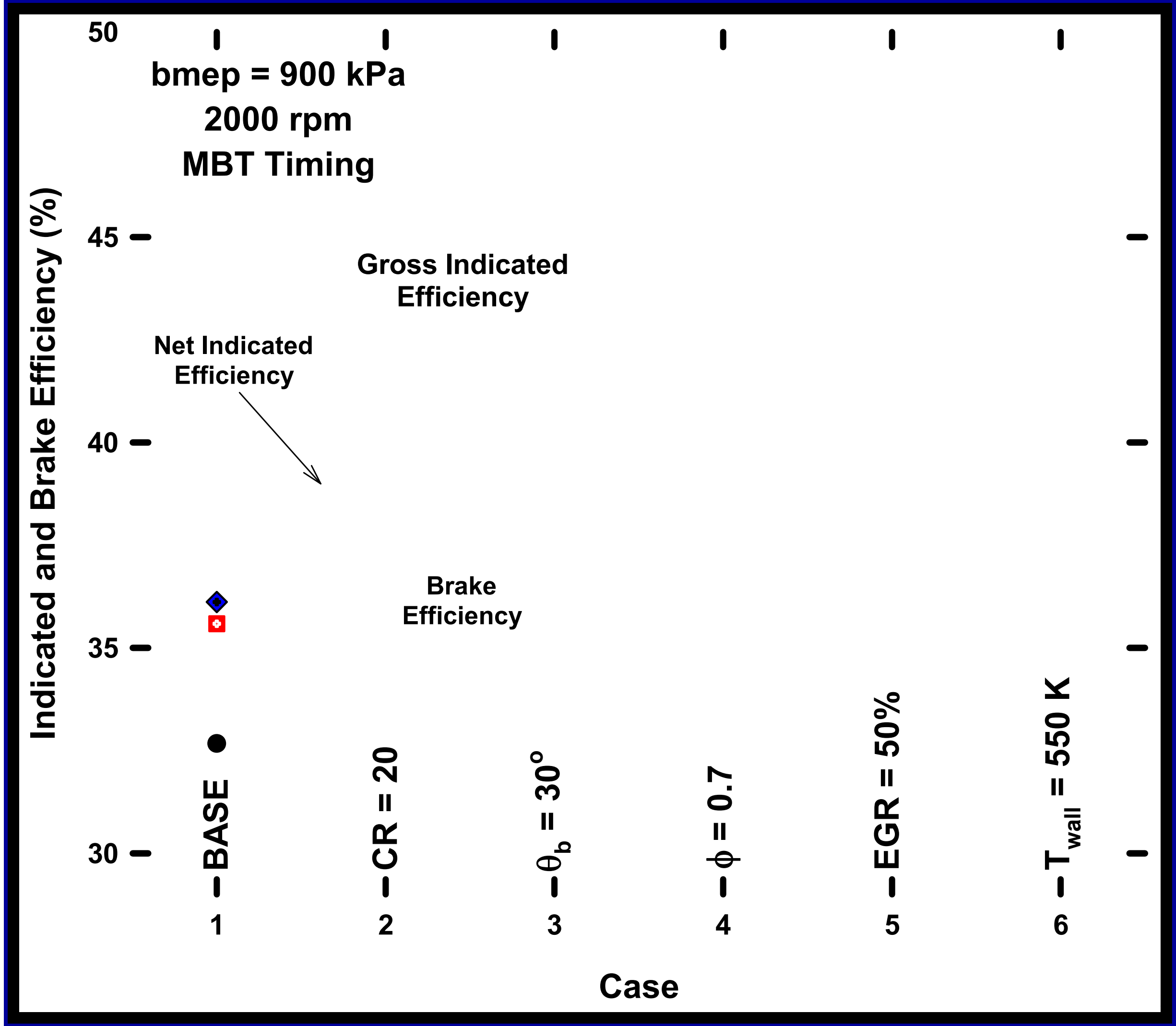
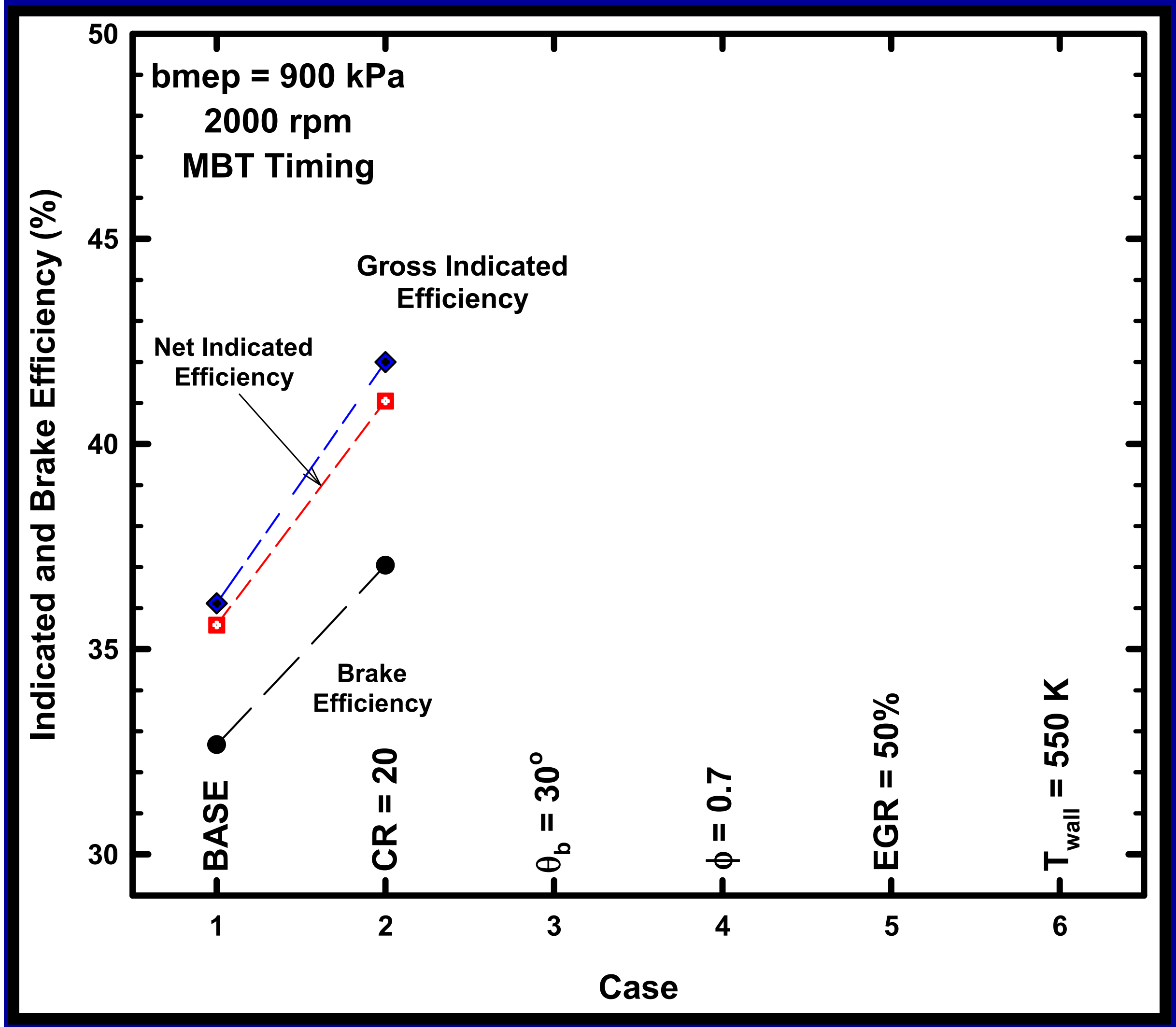
THERMAL EFFICIENCIES



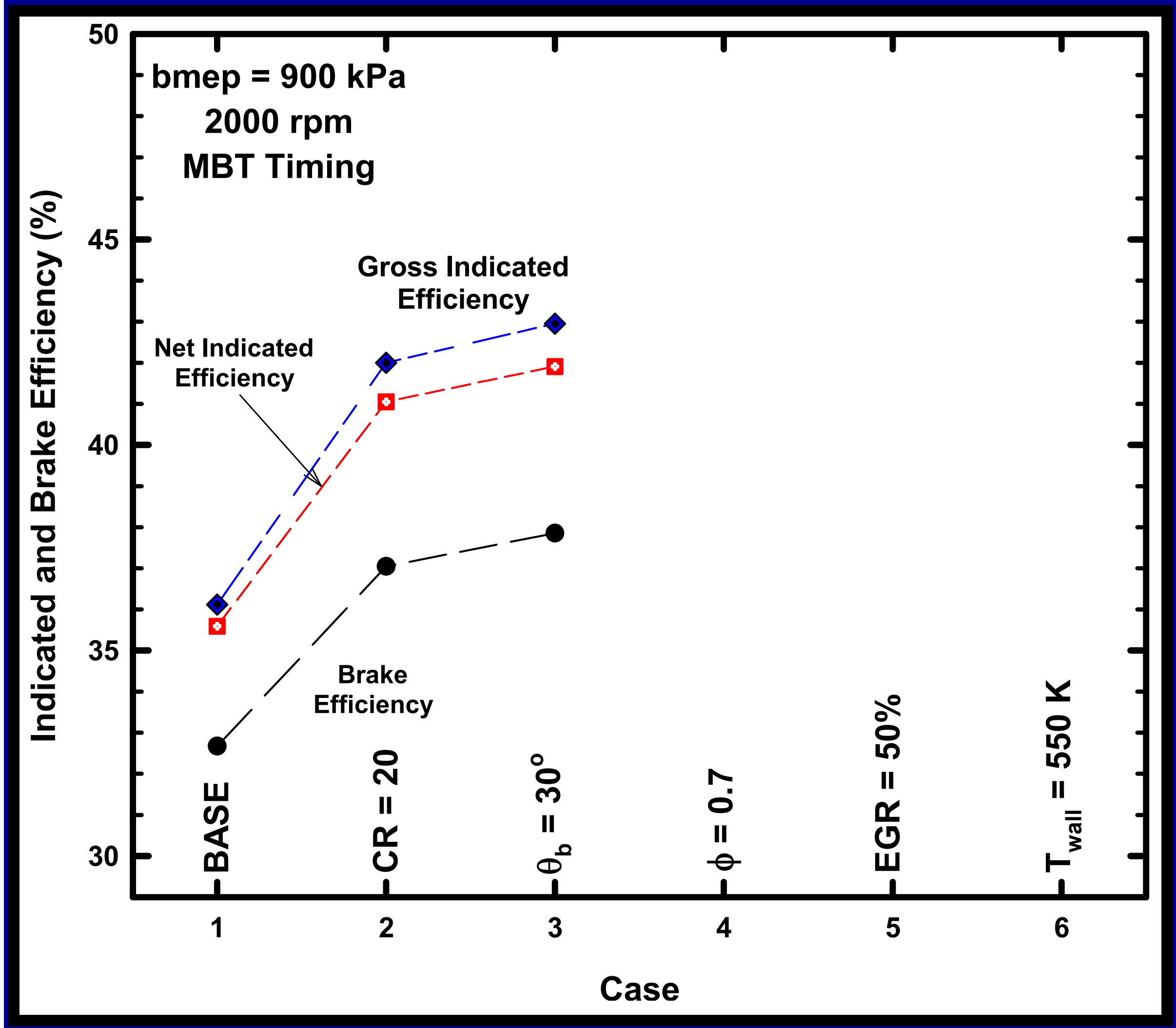
- Base Case

THERMAL EFFICIENCIES



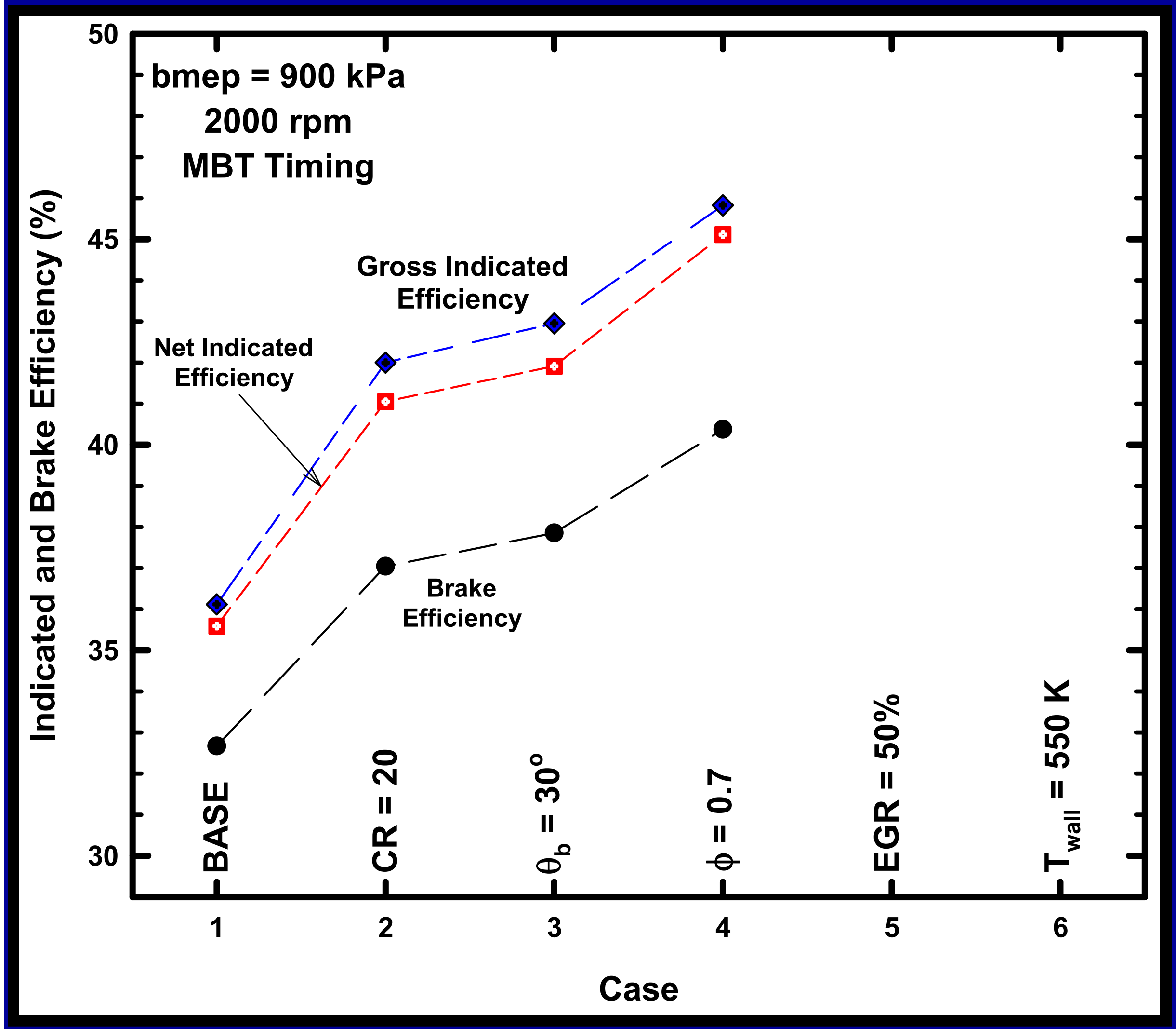
- **High compression ratio**

THERMAL EFFICIENCIES



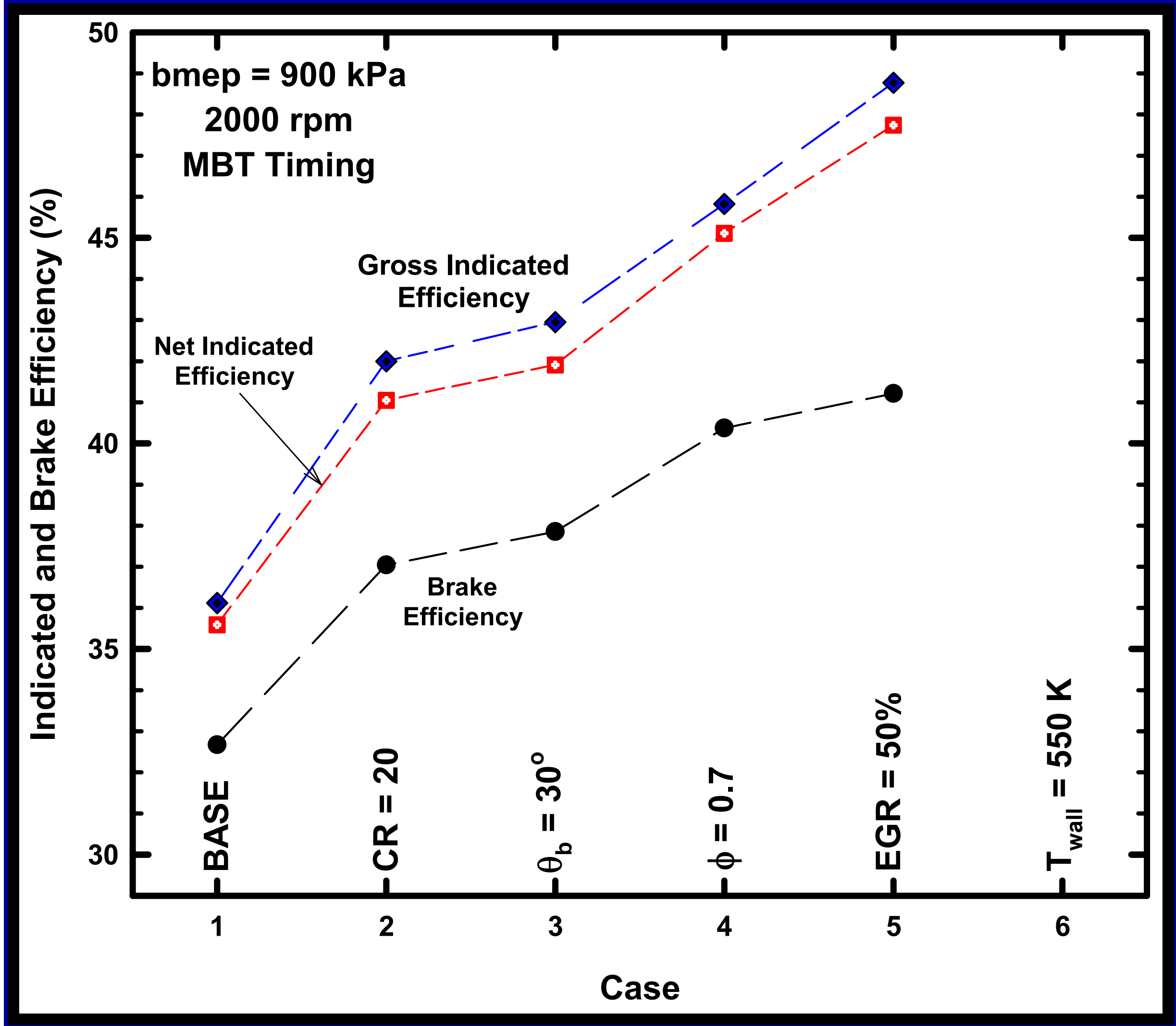
- High compression ratio
- Short burn duration

THERMAL EFFICIENCIES



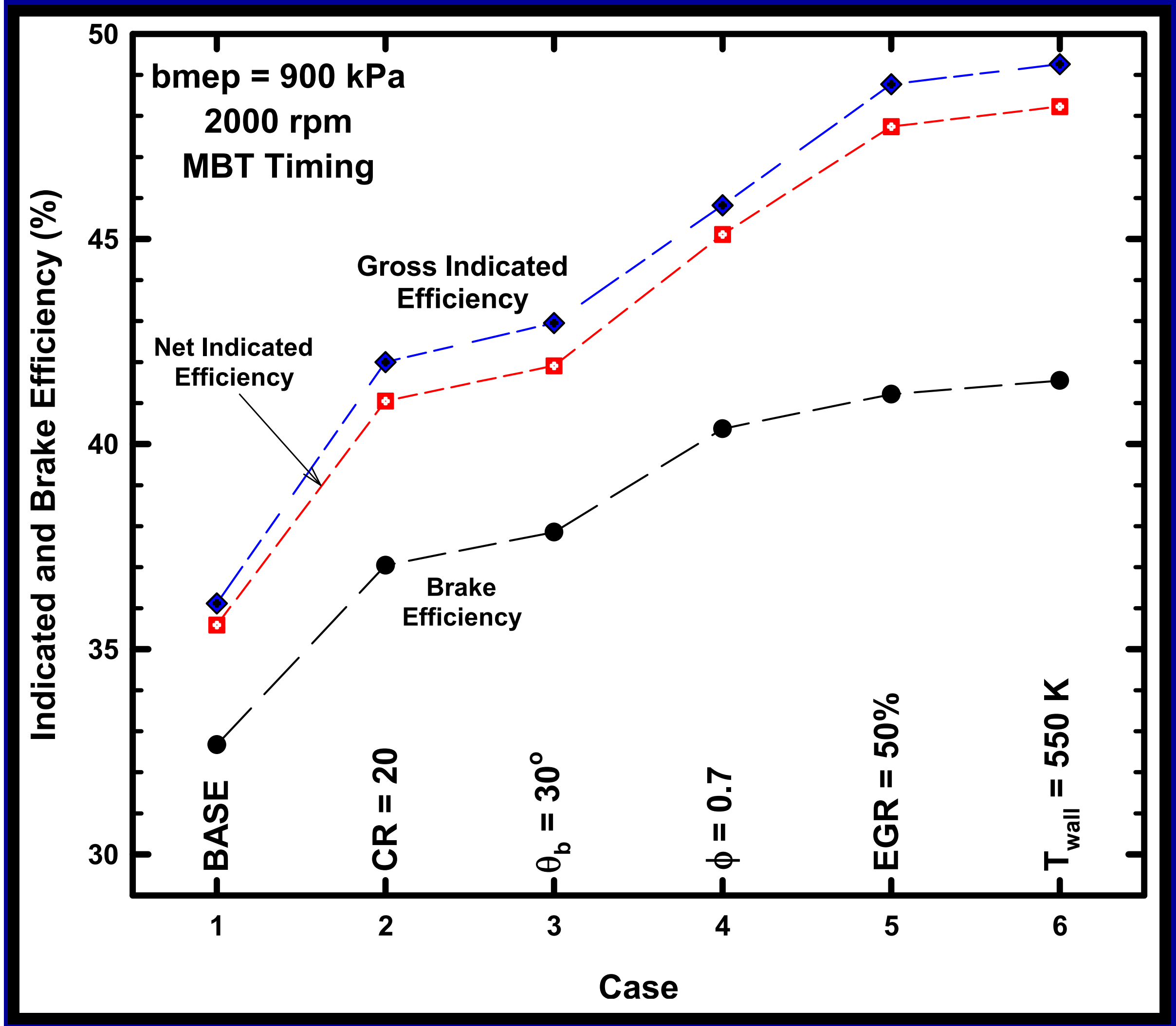
- High compression ratio
- Short burn duration
- Lean mixture

THERMAL EFFICIENCIES



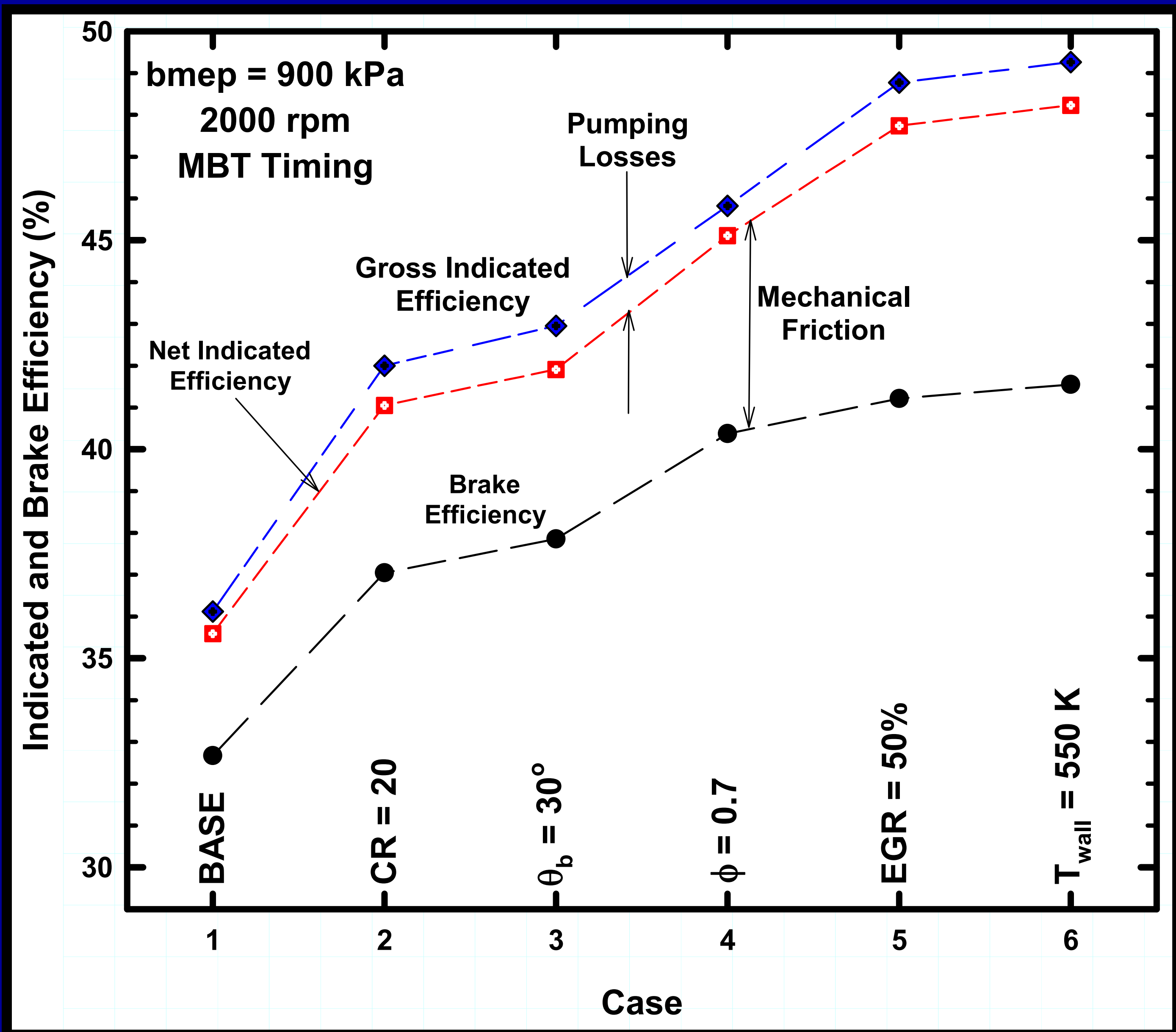
- High compression ratio
- Short burn duration
- Lean mixture
- High EGR

THERMAL EFFICIENCIES



- ➢ **High compression ratio**
- ➢ **Short burn duration**
- ➢ **Lean mixture**
- ➢ **High EGR**
- ➢ **High cylinder wall temp**

THERMAL EFFICIENCIES



RESULTS

Case 6:

$\eta_{ind,g}$ = 49.5%

$\eta_{ind,n}$ = 48.2%

η_{brk} = 41.6%

Case 1:

$\eta_{Ind,g}$ = 36.1%

$\eta_{ind,n}$ = 35.6%

η_{brk} = 32.7%

COMPARISON TO THE LITERATURE

ITEM	REFERENCE (Kokjohn et al.)	THIS WORK (Case 6)
Bore/Stroke (mm)	137/165	102/88
Fuels	Gasoline/Diesel	Isooctane
Inlet Pressure (kPa)	200	227
Geometric CR	16.1	20
EGR (%)	45.5	50
Equivalence Ratio	0.77	0.7
Speed (rpm)	1300	2000
RESULTS:		
$IMEP_{NET}$ (kPa)	1100	1047
Net Ind Efficiency (%)	50	48.2
Peak Pressure (MPa)	12	13.9
Nitric Oxide (g/kW-h)	0.01	0

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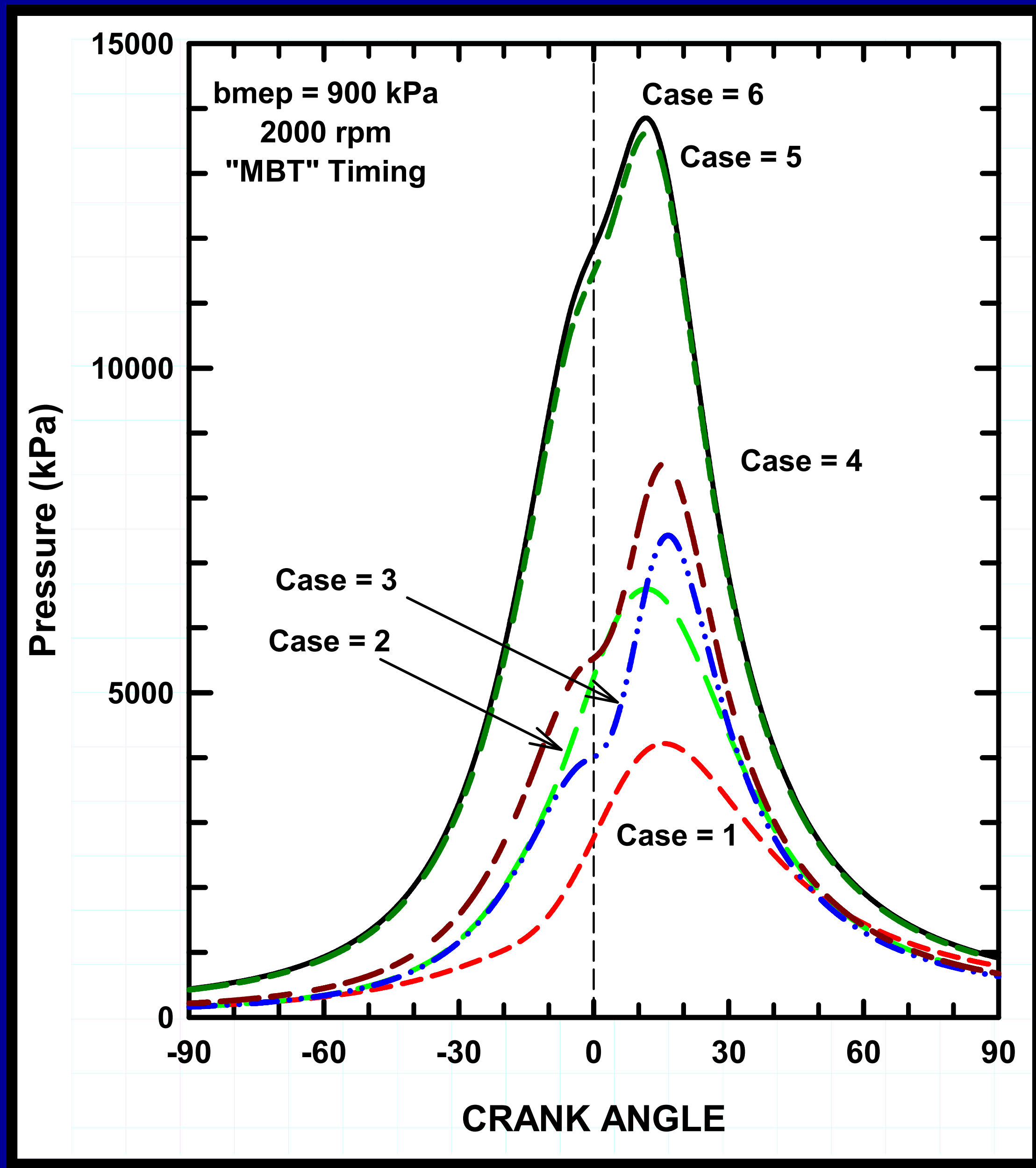
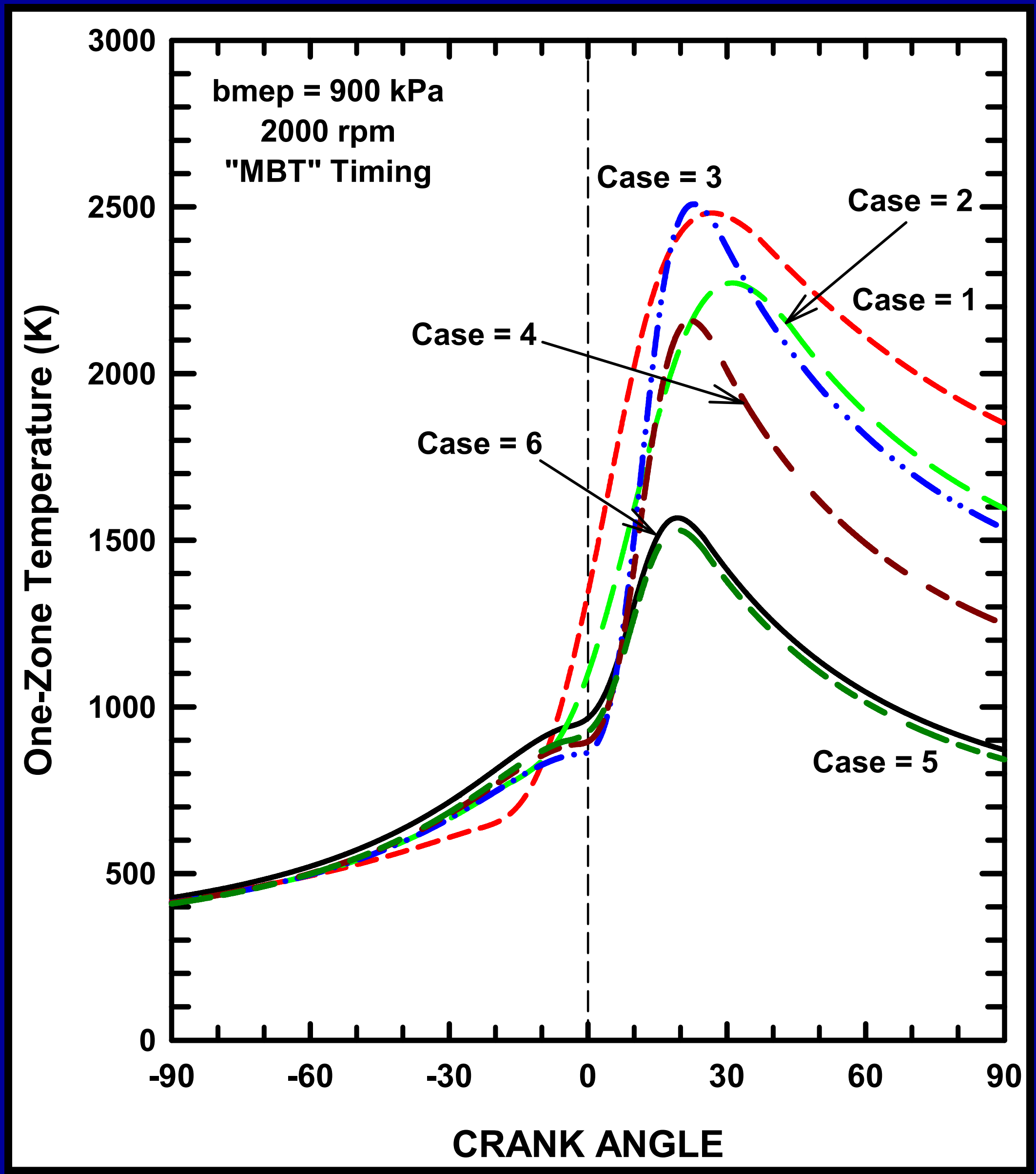
CYLINDER PRESSURES



CYLINDER TEMPERATURES



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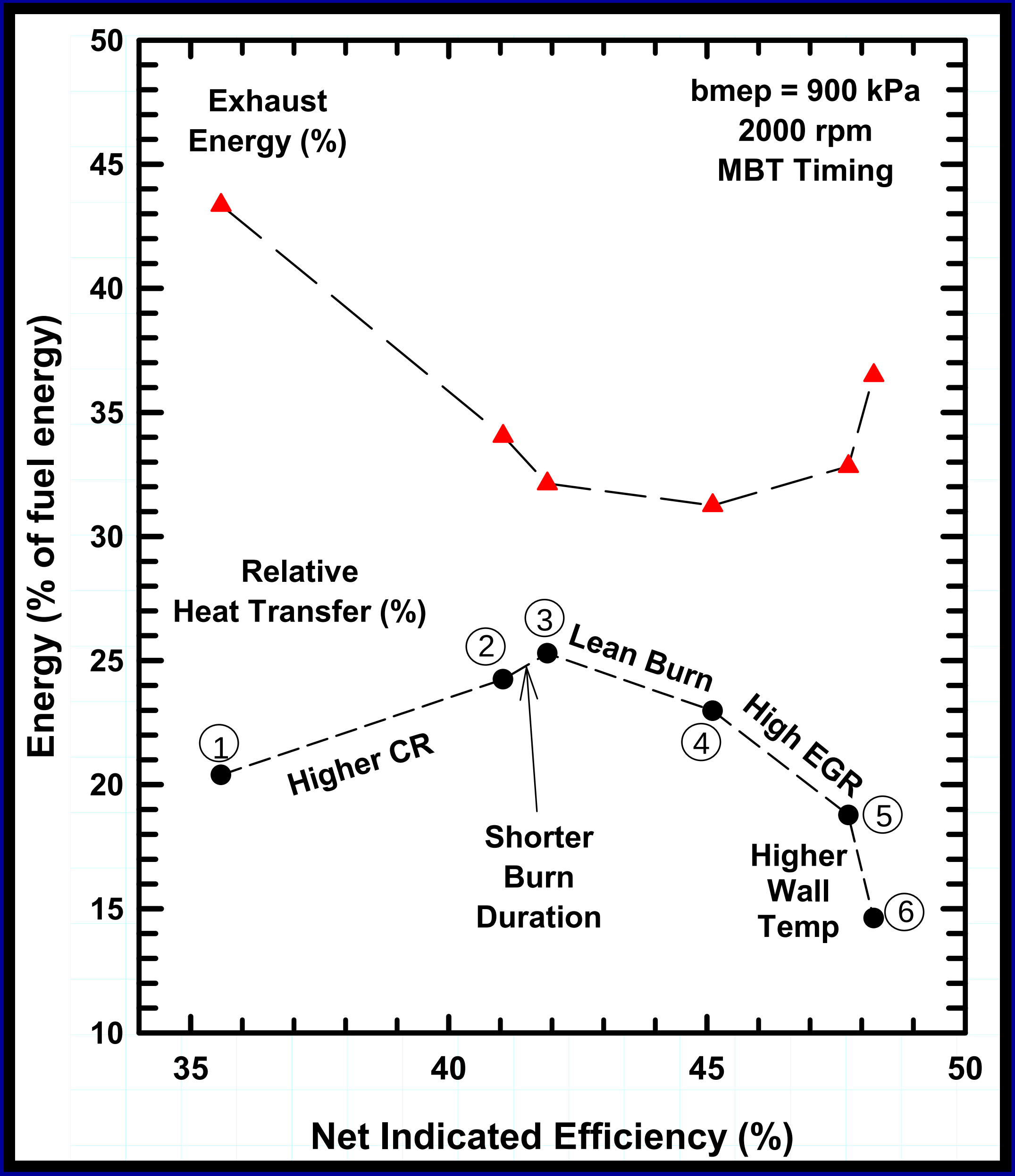
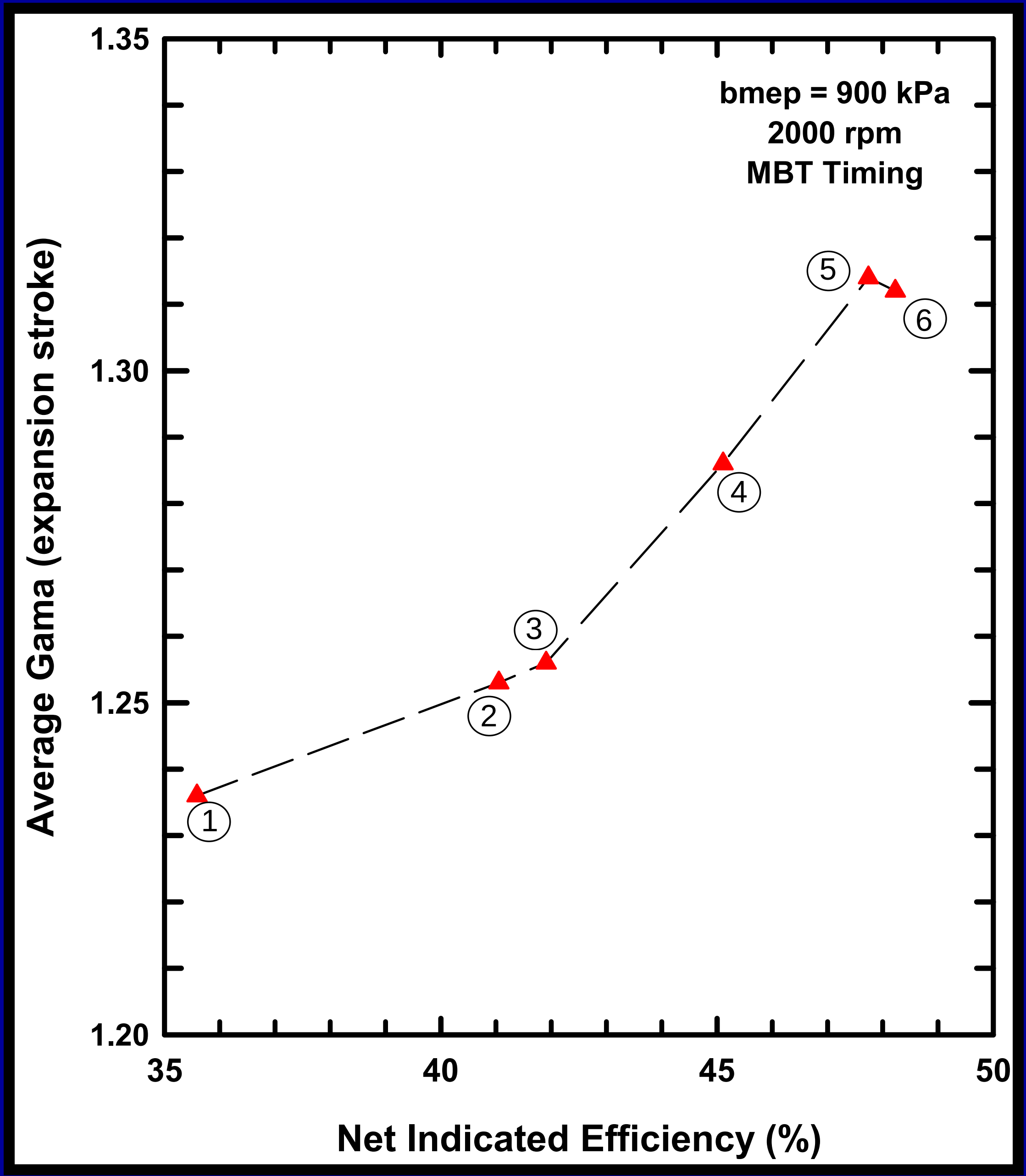
HEAT TRANSFER AND EXHAUST ENERGY



Average "gamma" for Expansion Stroke



Note: from simple "Otto" cycle considerations –

a "0.01" increase of gamma results in about a 1% efficiency gain

This implies that about one-half to two thirds of the efficiency increases are due to the increase of gamma.

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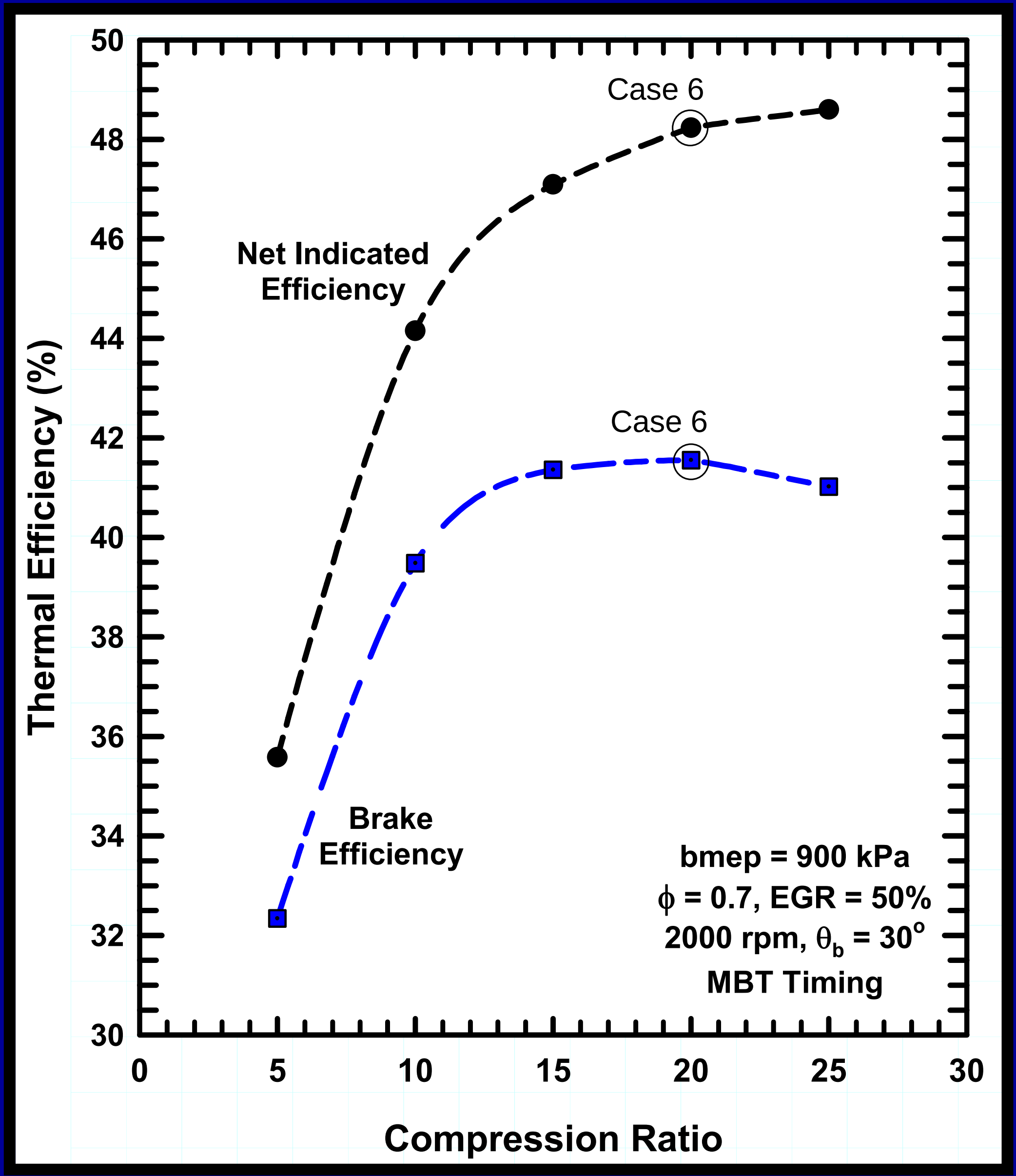
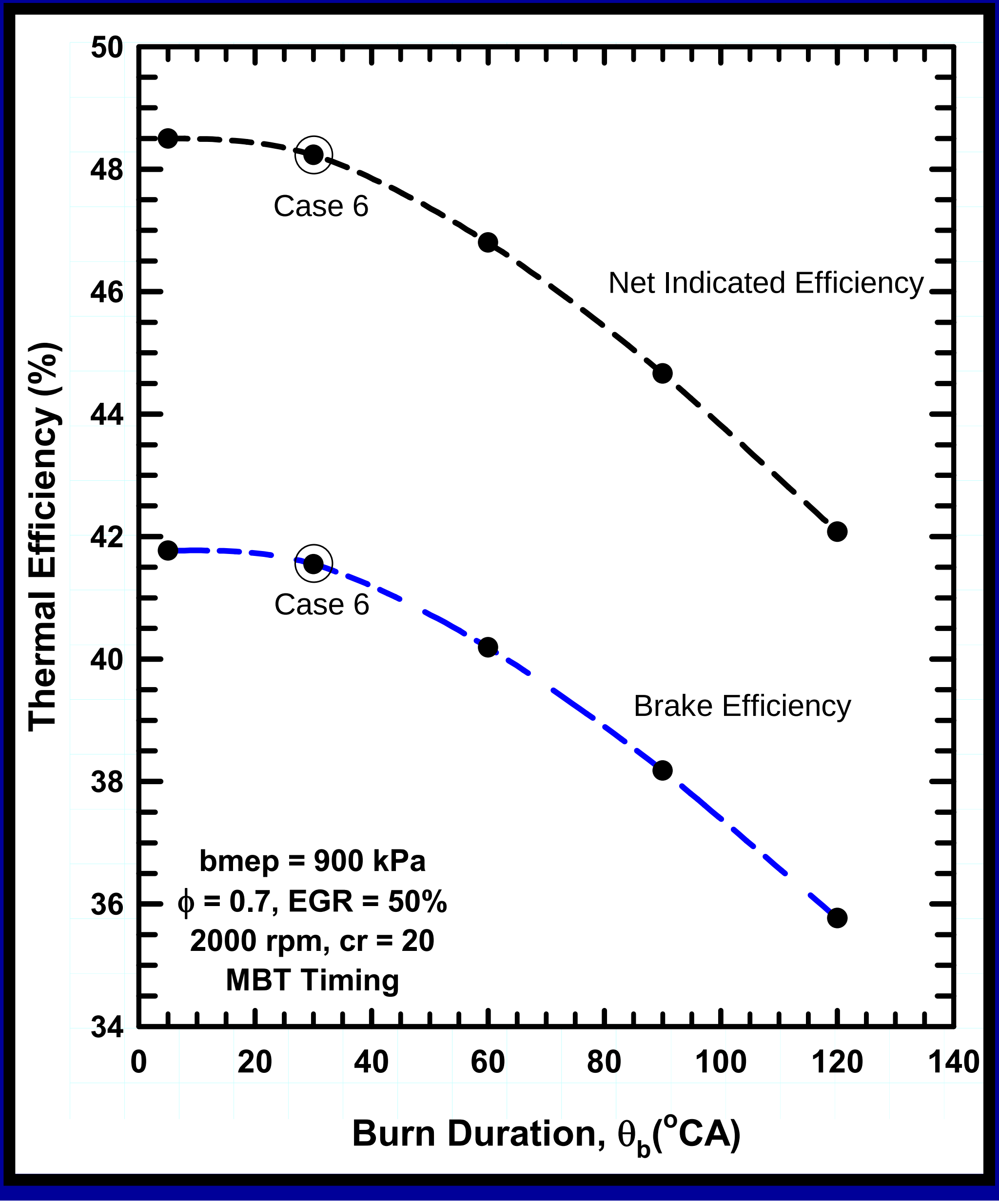
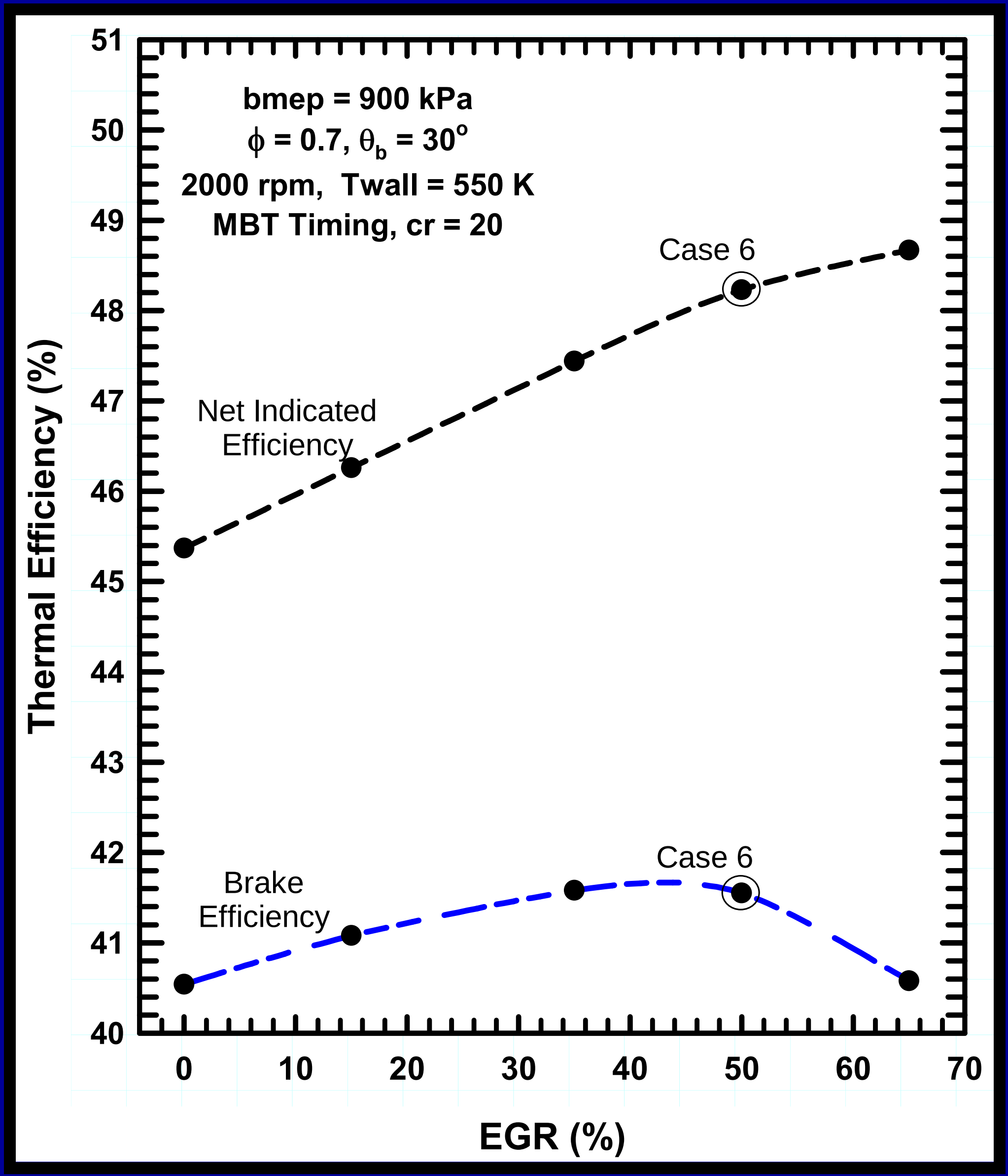
EFFECTS OF COMPRESSION RATIO



EFFECTS OF BURN DURATION



EFFECTS OF EGR



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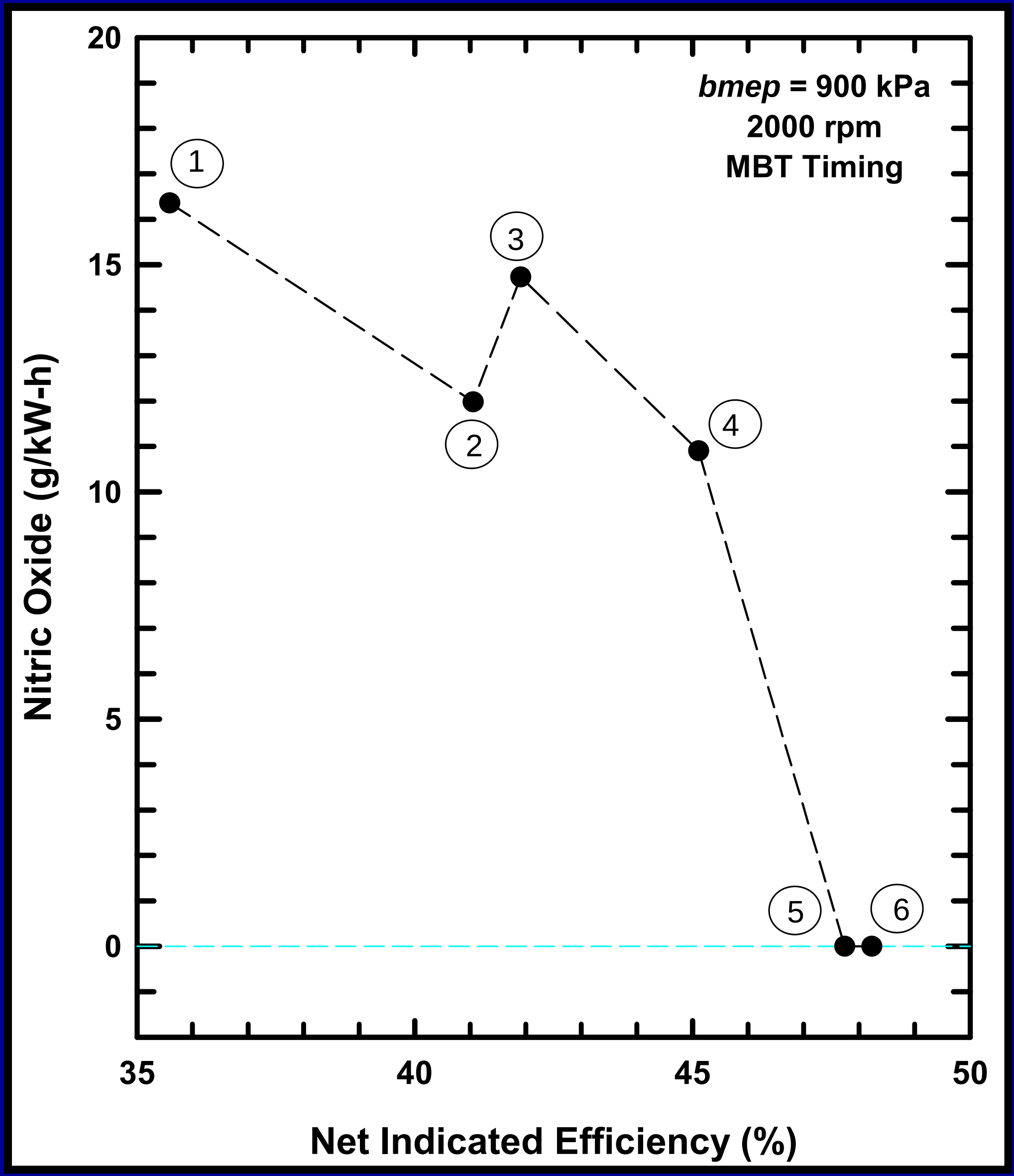
NITRIC OXIDES FOR EACH CASE



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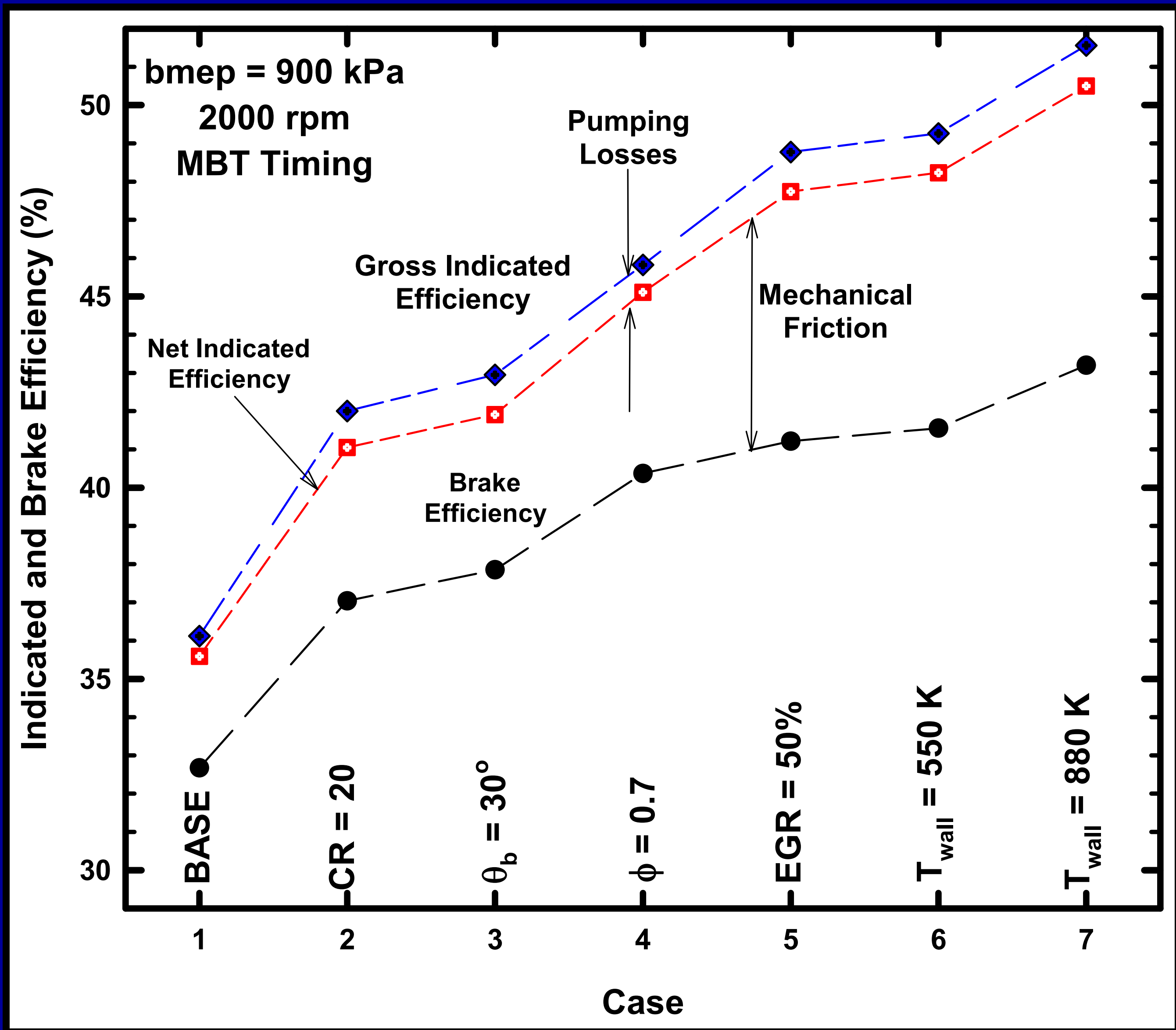
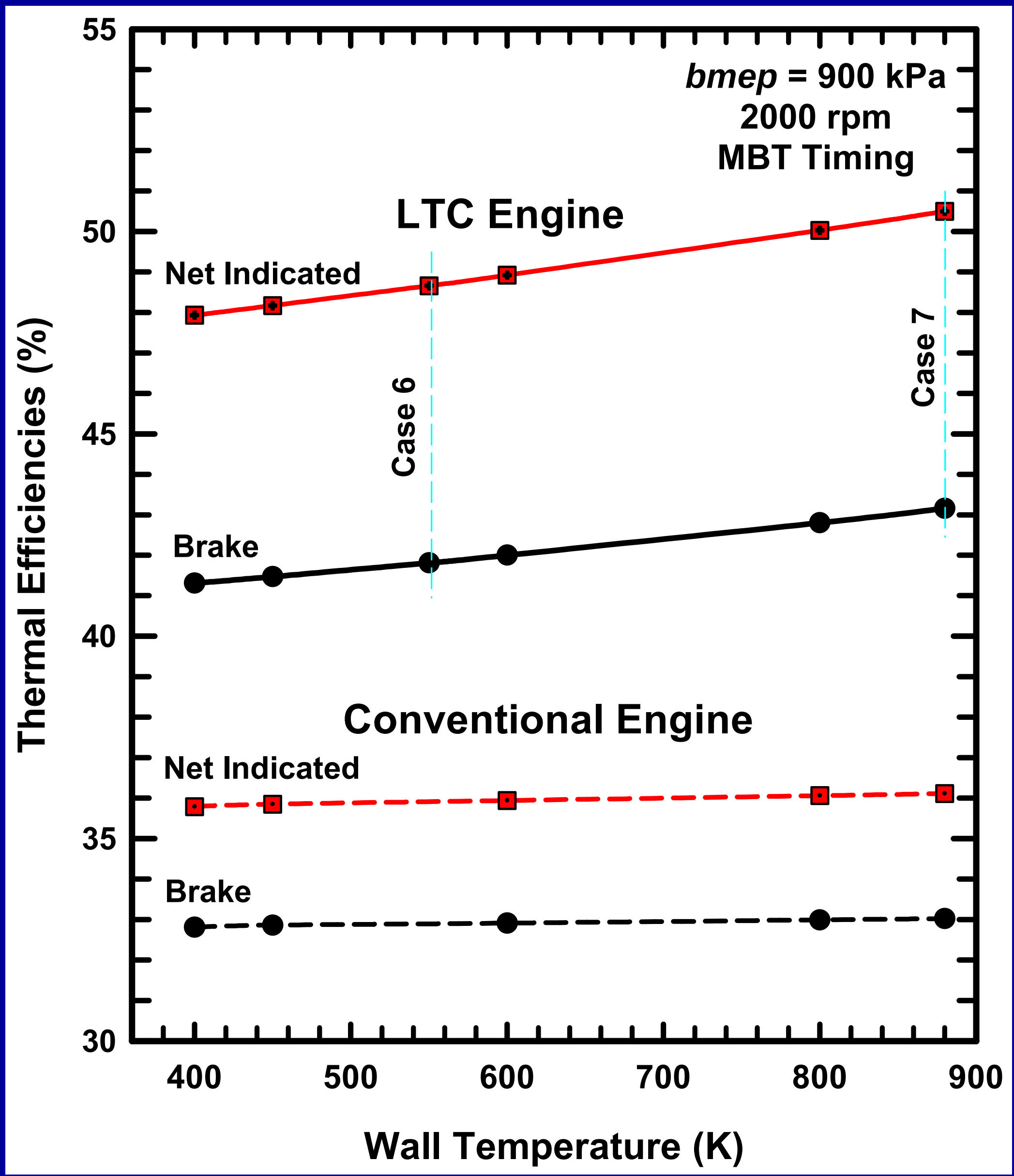
LOW HEAT REJECTION (LHR)



LOW HEAT REJECTION (LHR)



Other Conditions

- Other operating conditions exhibit similar improvements
- For different “order” of features – same final result, but incremental gains slightly different
- For reduced heat transfer without higher wall temperatures, even higher gains are possible

CONCLUSIONS (1/2)

- High CR, high EGR, lean mixtures and other features can combine to yield ~50% net indicated thermal efficiency
- Features of most importance: CR, EGR, lean mixtures
- The major reasons for the higher efficiencies include the lower heat transfer, the higher "gamma," and the high CR
- To maintain load, higher cylinder pressures result and the associated mechanical friction increases

CONCLUSIONS (2/2)

- The lower exhaust gas energy may cause the application of turbochargers to be problematic
- Low heat rejection (LHR) concepts are more compatible with LTC engines than with conventional engines
- Predicted nitric oxides are “zero” for the LTC modes
- Exergy destruction during combustion increases largely due to the lower temperatures – this is an acceptable trade-off for the higher efficiencies