INTEGRAL APPROACH FOR OPTIMUM OPERATION OF DIESEL AFTERTREATMENT DEVICES

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OUTLINE

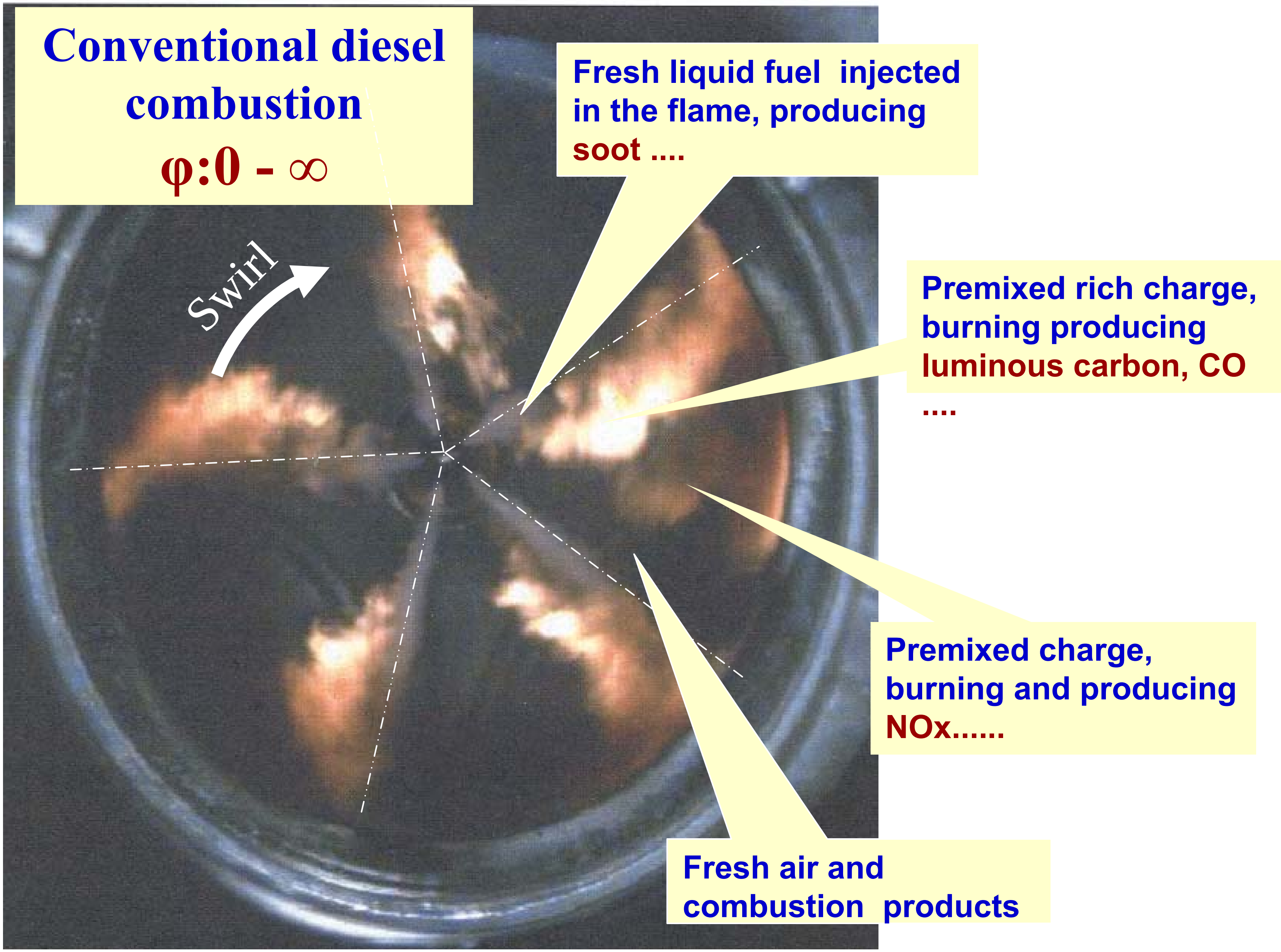
- Background
- Goal
- Conventional Diesel Combustion and Engine-Out Emissions
- Experimental engine and instrumentation
- OPERAS for Integrated Engine and After Treatment Devices :CDPF, LNT, CRT
- LTC Concepts: MK, UNIBUS, Smokeless Rich Combustion.
- WSU (LTC-OT) system
- Conclusions

GOAL

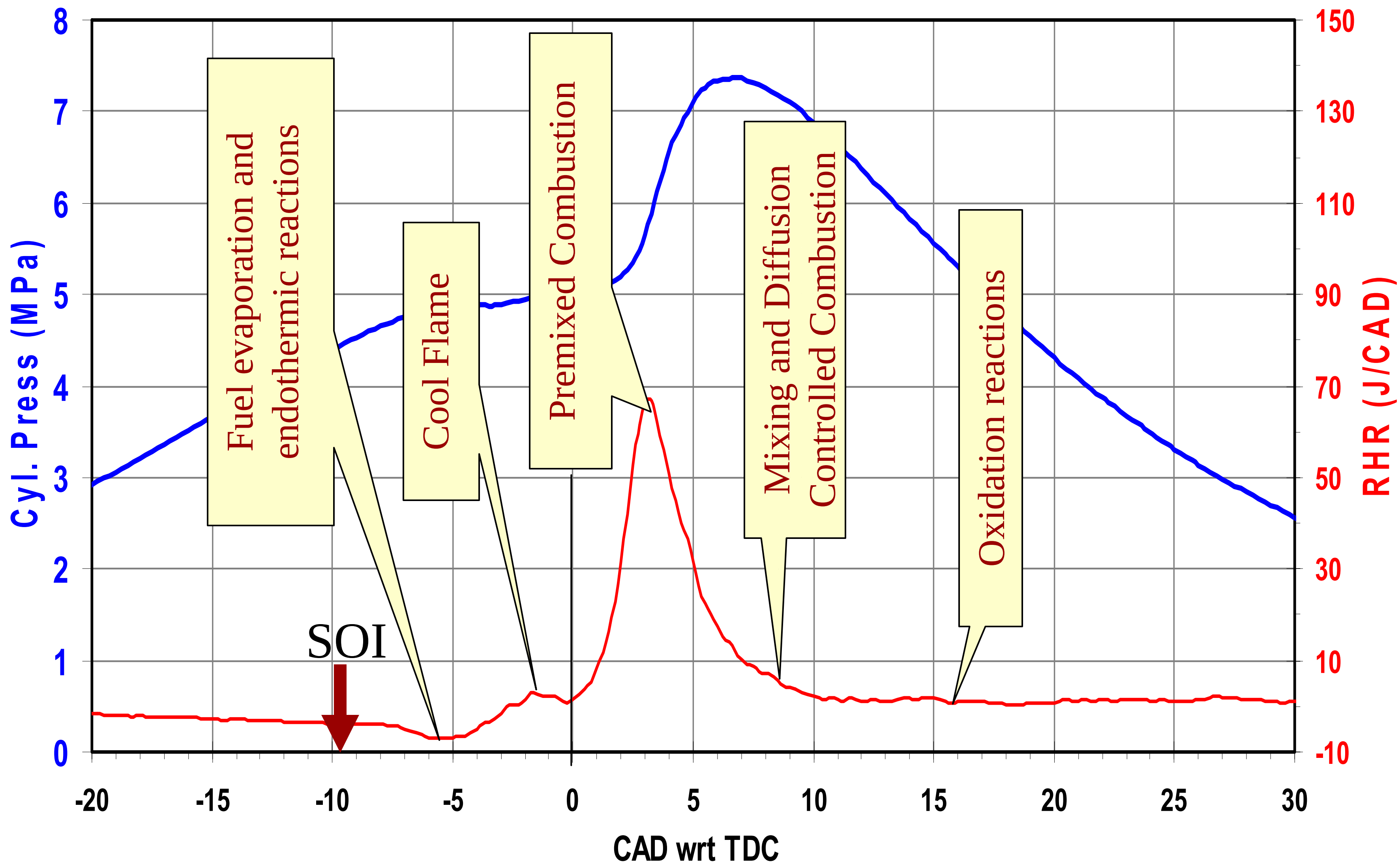
To investigate the engine control strategies needed for the efficient operation of the after treatment devices under different combustion regimes, including the conventional and low temperature combustion concept (LTC) reaching the smokeless, NOxless operation.

- MK (Modulated Kinetics) system and associated problems
- Smokeless Rich Combustion system
- LTC-WSU

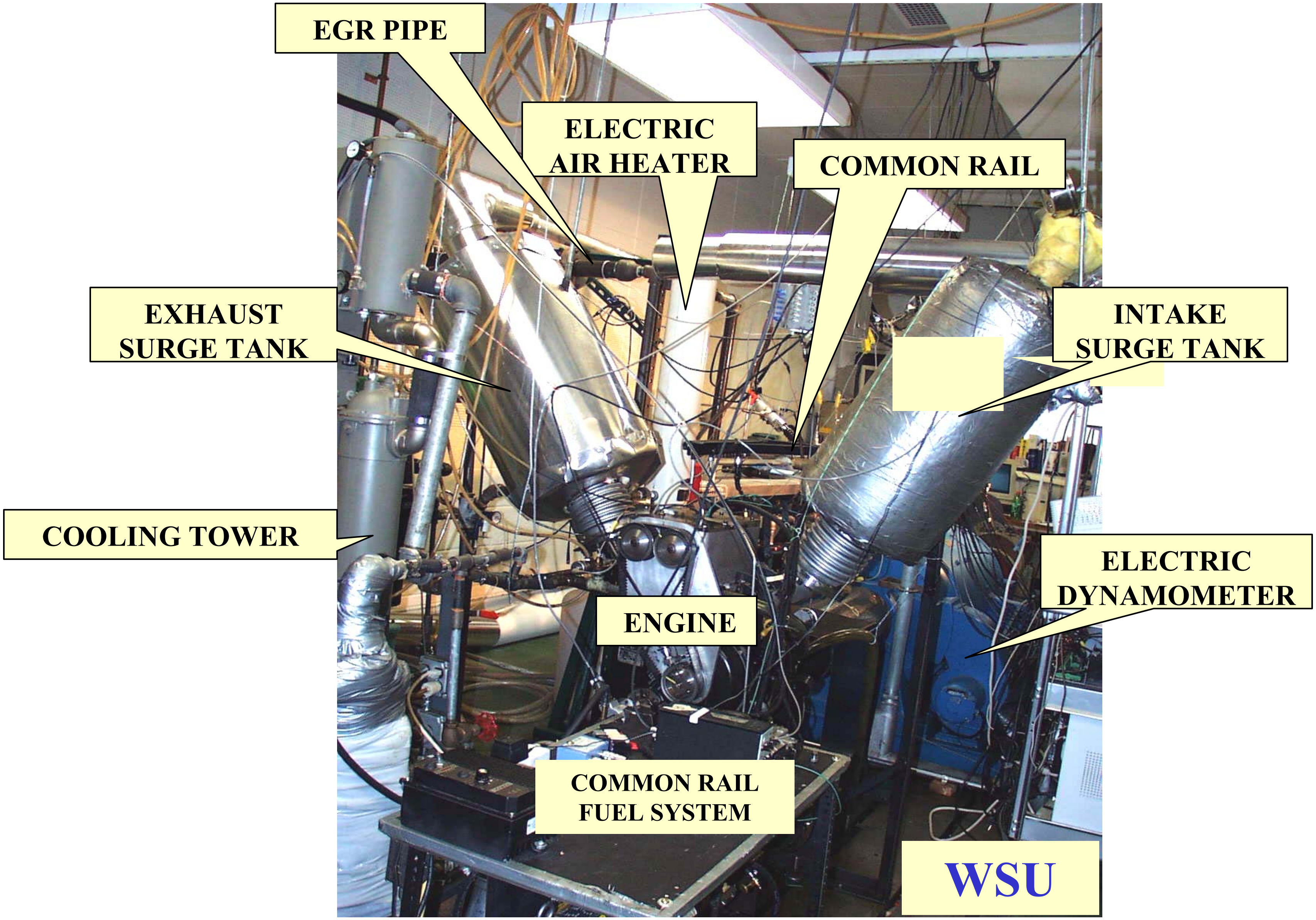
Conventional Diesel Combustion


Conventional diesel combustion
φ:0 - ∞
Swirl
Fresh liquid fuel injected in the flame, producing soot ....
Premixed rich charge, burning producing luminous carbon, CO ....
Premixed charge, burning and producing NOx......
Fresh air and combustion products

Sample cylinder pressure & RHR traces
Conventional Diesel Combustion



Single-cylinder High Speed Direct Injection Diesel Engine

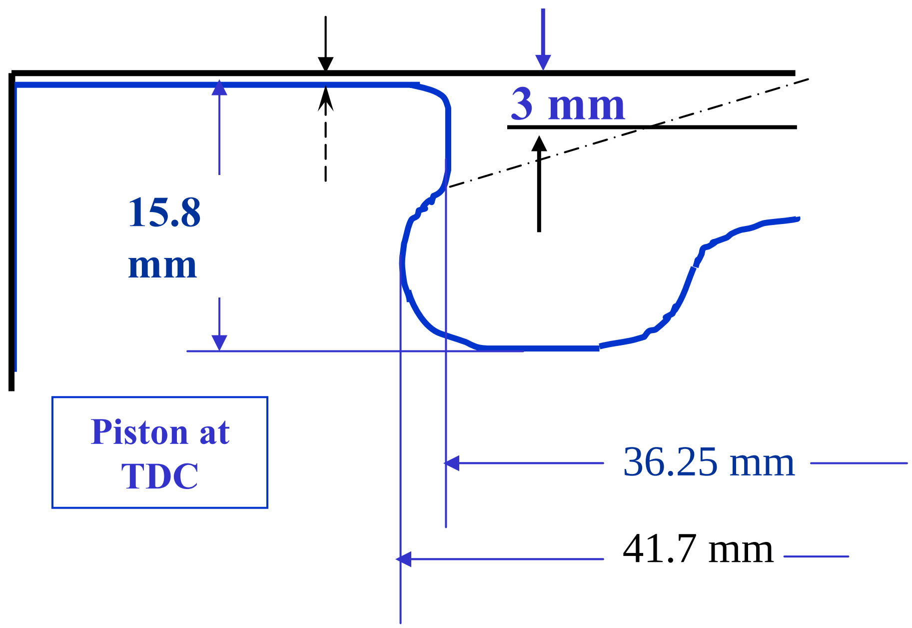


ENGINE & COMBUSTION SYSTEM

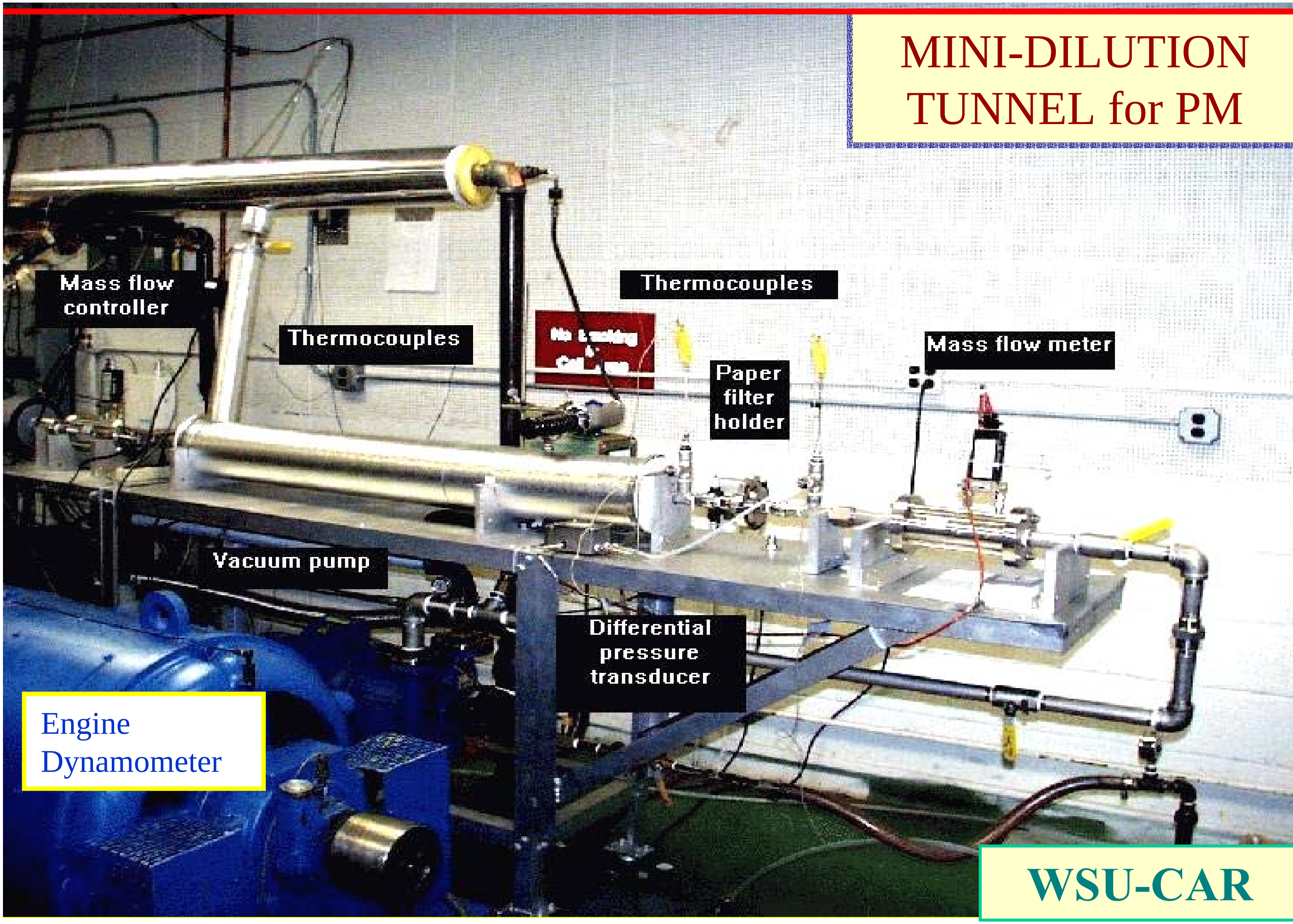
- Single-cylinder, d = 79.5 mm, L = 85mm, 4-V, C.R.= 20:1, supercharged.
- Swirl Ratio: 1.4 – 7.12

(Gate on the tangential port is closed to increase SR: 90 is full open)

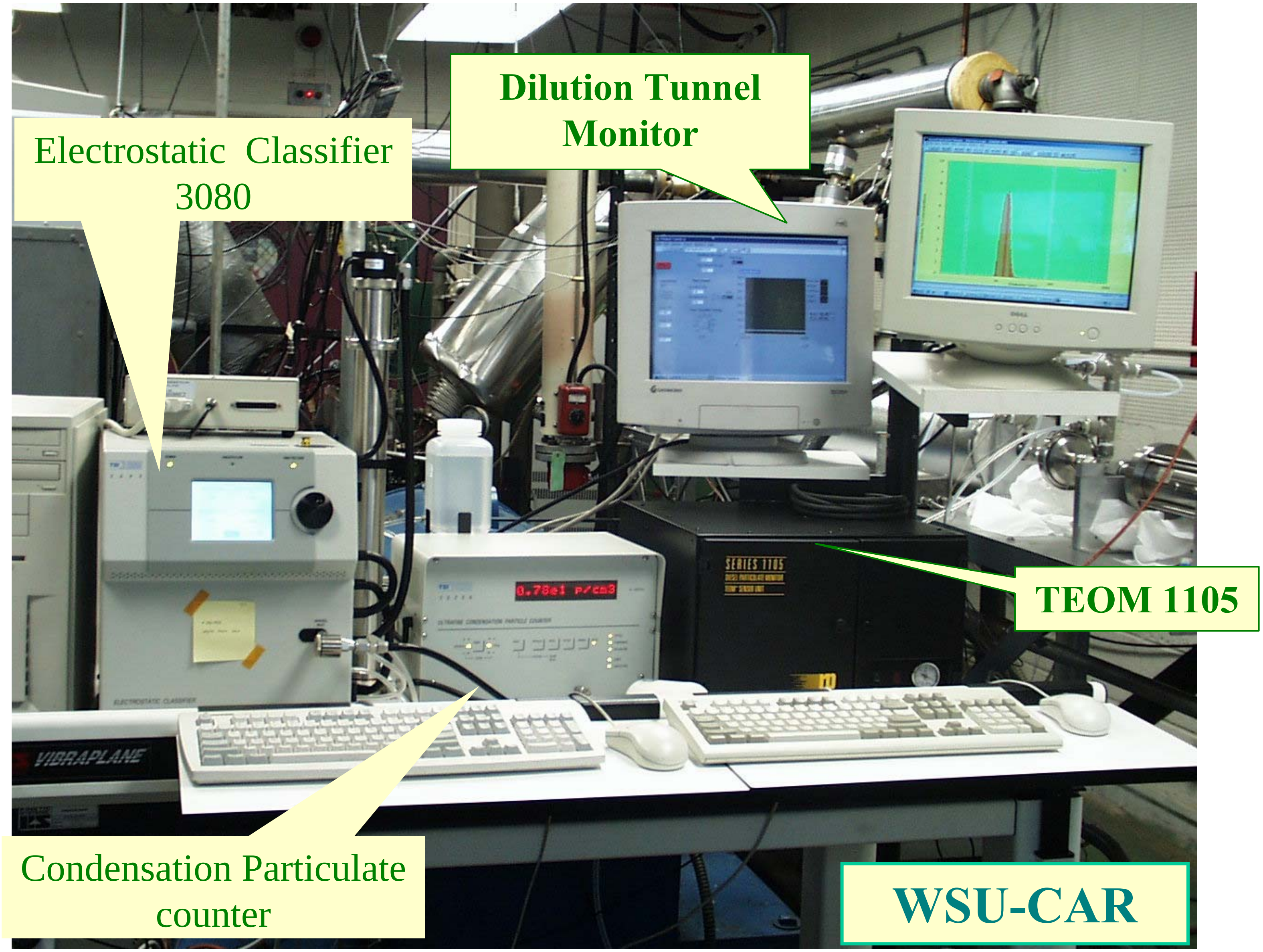
- High Squish Flow
- Common Rail Injection system, peak pressure = up to 1300 bar
- Nozzle: VCO, **Mini-Sac**



PARTICULATE MATTER INSTRUMENTATION



PARTICULATE MATTER INSTRUMENTATION



EMISSIONS INSTRUMENTATION

HORIBA MEXA 7100 DEGR

HIGH PRESSURE LIQUID CHROMATOGRAPHY TO MEASURE ALDEHYDES

GAS CHROMATOGRAPH

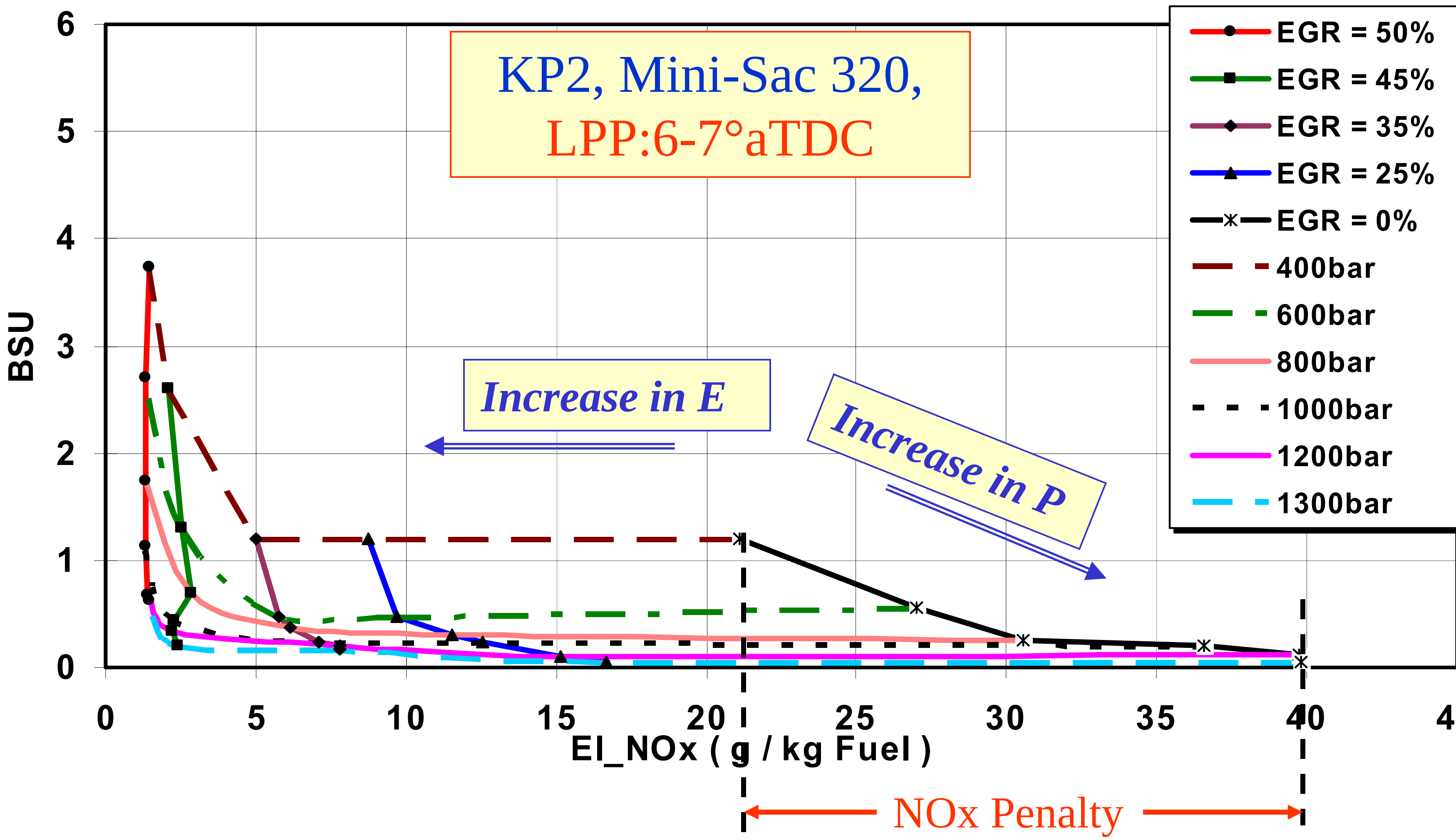
Test Matrix

	RPM	IMEP(Bar)	MAP(Bar	
KP1:	**900**	**1.2**	**1.0**	
KP2:	**1500**	**3.0**	**1.2**	
KP3:	**2000**	**5.0**	**1.4**	
LTC:	**2000**	**7.0**	**1.4**	**MK**
LTC:	1500	**3.00**	**1.2**	**WSU**

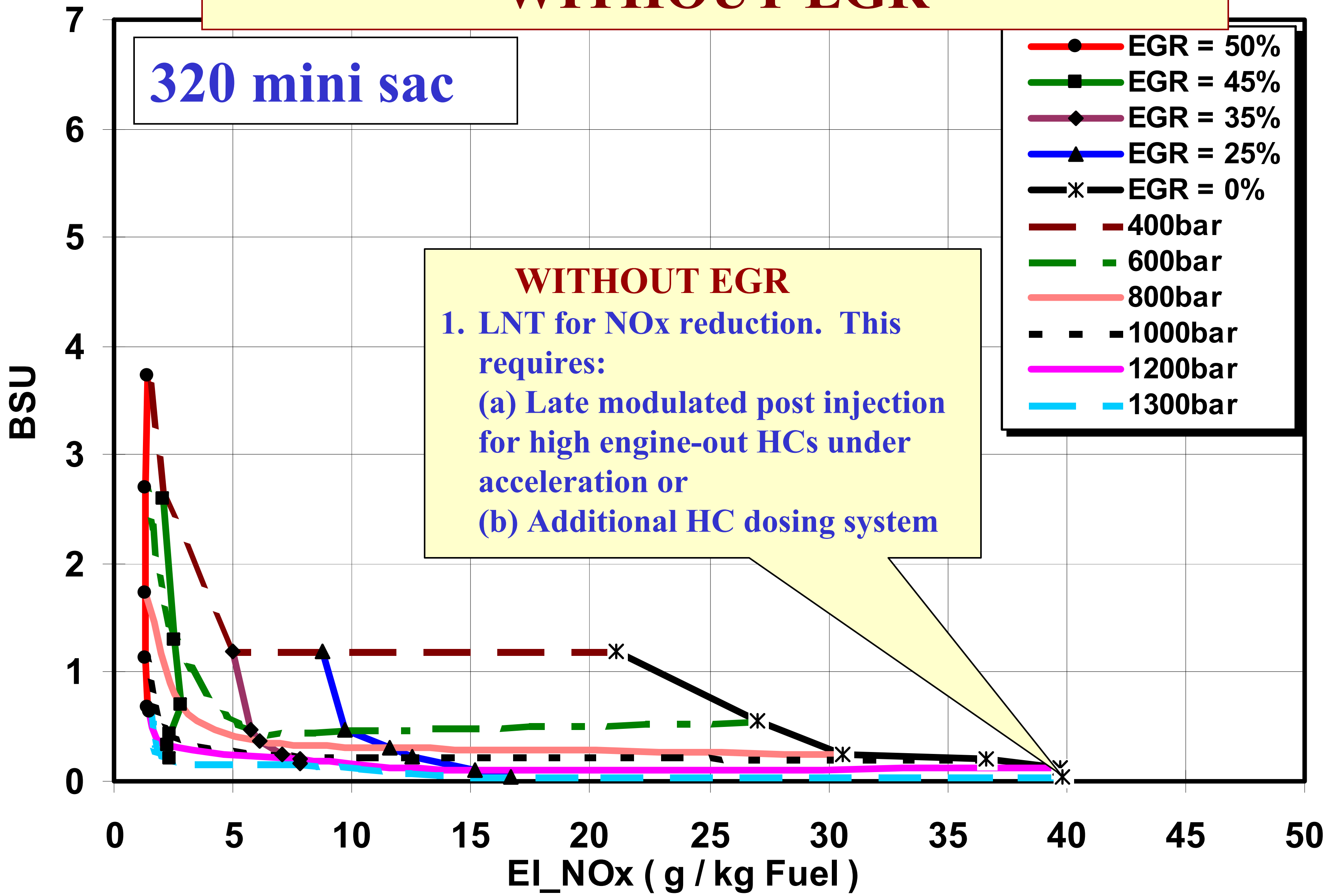
ENGINE OPERATING PARAMETERS

- Injection Pressure
- EGR
- Retard or Advance timing
- Swirl Ratio

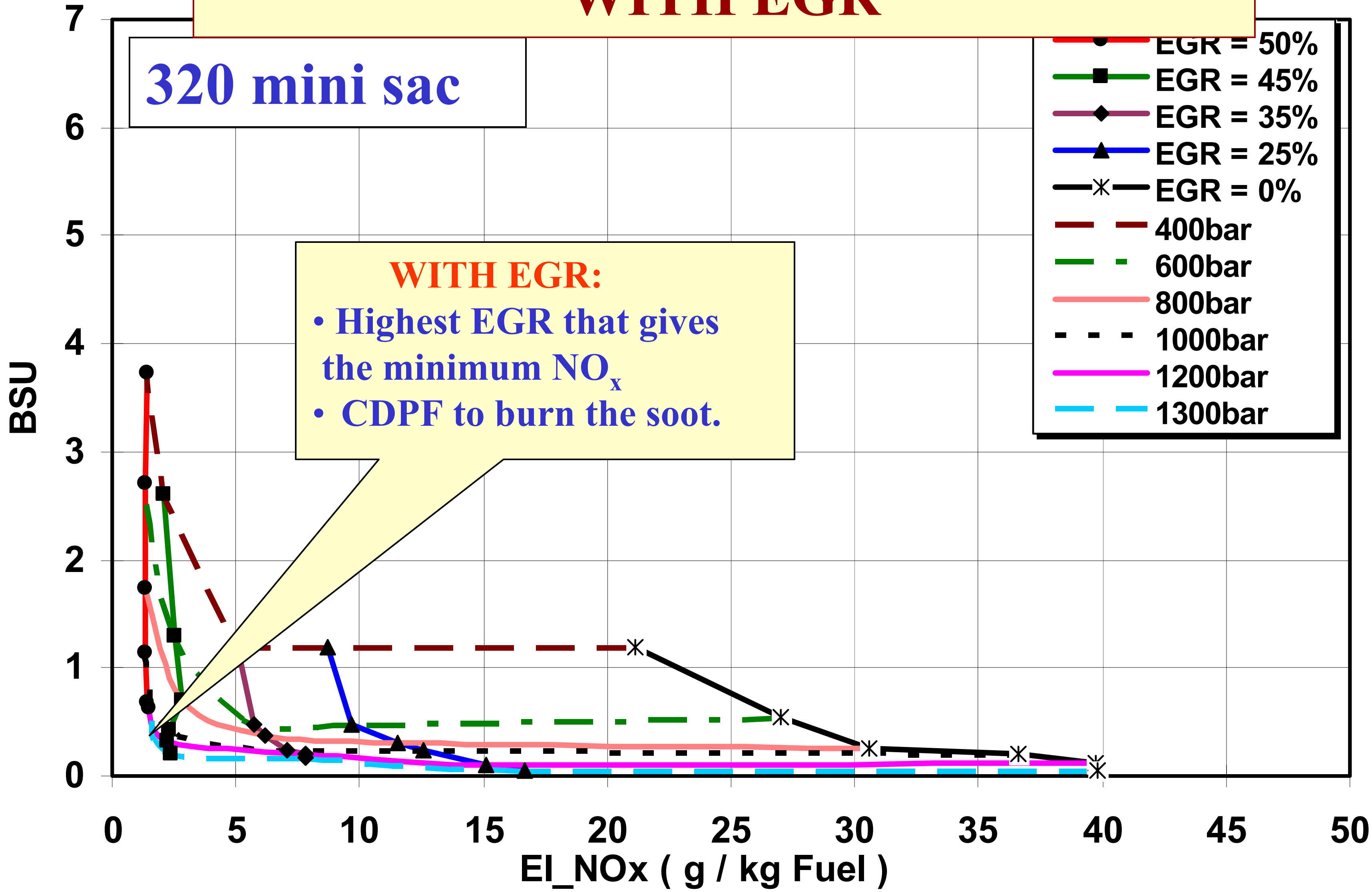
EFFECT OF Pinj and EGR on the TRADE-OFF between BSU and NOx



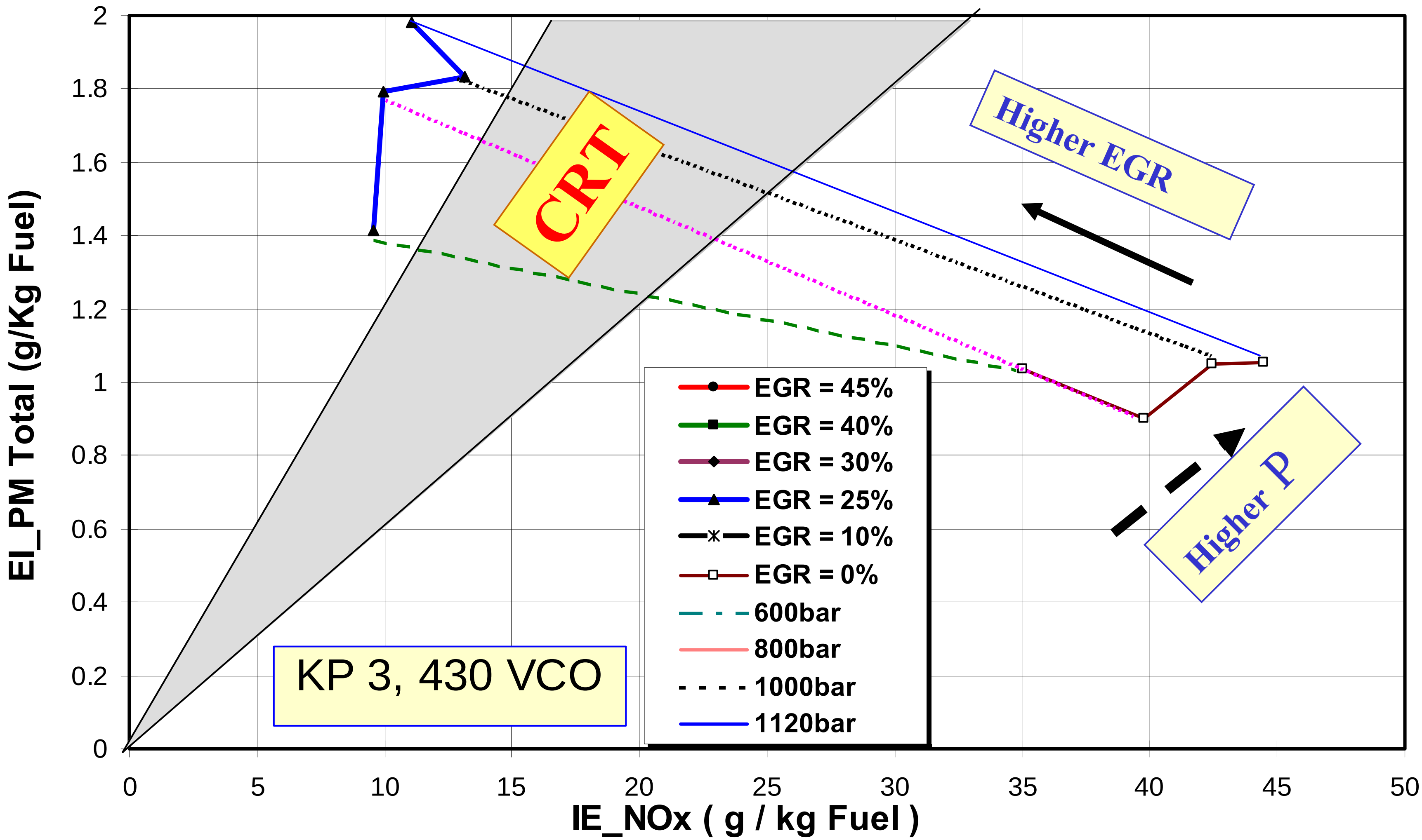
OPERAS FOR SYSTEM CONTROL WITHOUT EGR



OPERAS FOR SYSTEM CONTROL WITH EGR



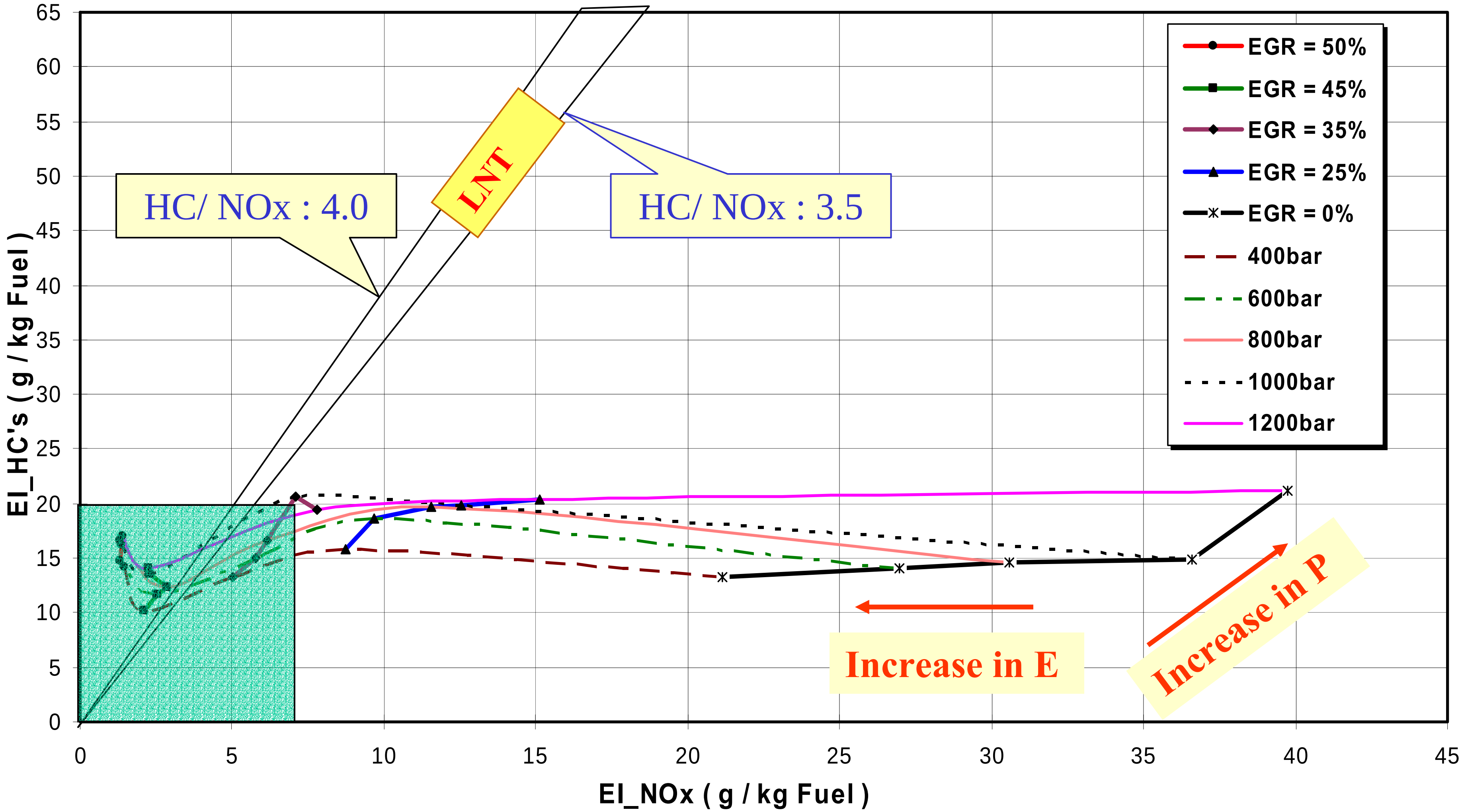
OPERAS FOR PROPER [NO_x /C] FOR CRT OPERATION



RPM = 2000, IMEP = 500kPa, Tin = 350k, Pin = 1.4bar, Pexh = 1.8bar, Angle of Ppeak:6-7ATDC

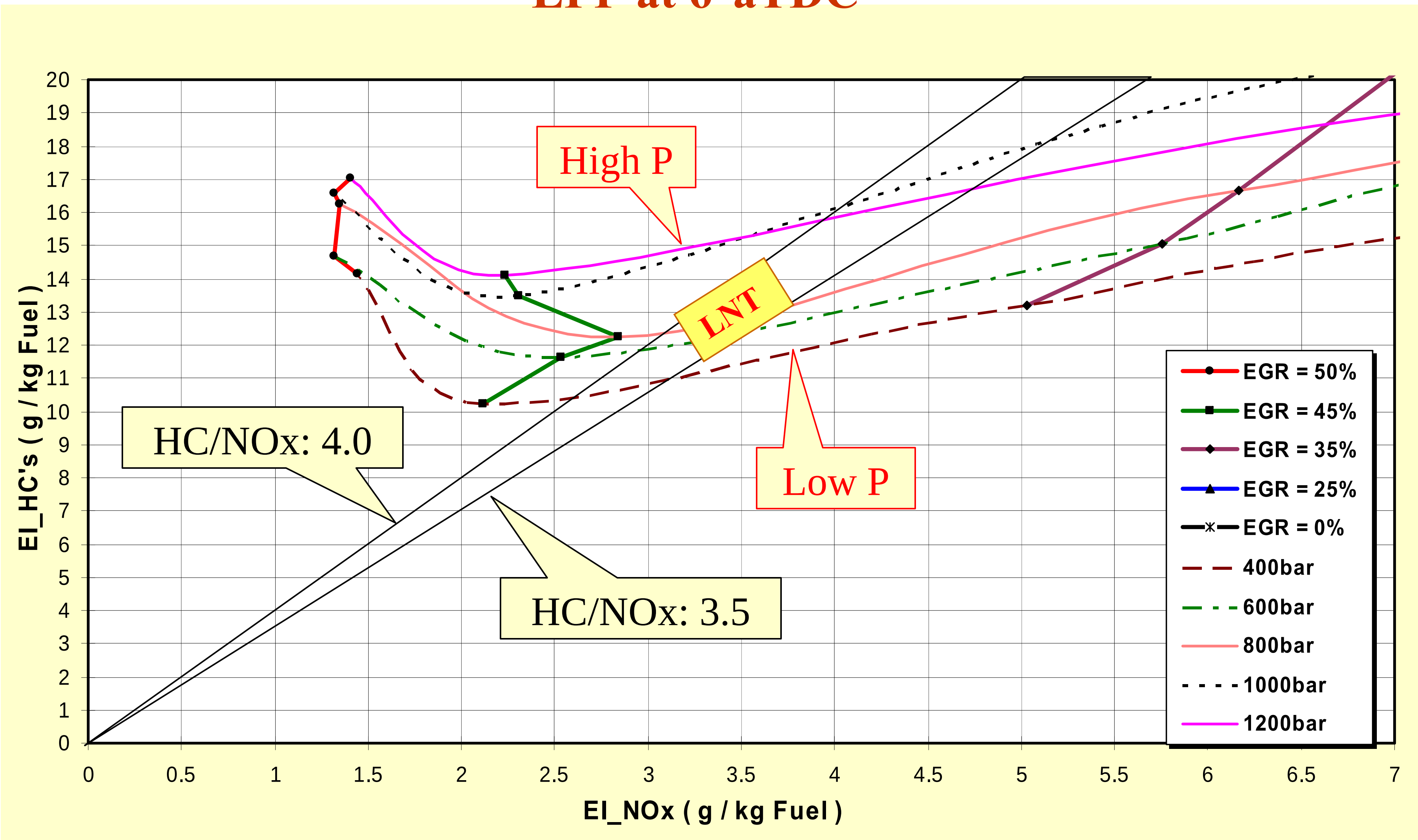
OPERAS FOR PROPER [NO/HC] FOR LNT OPERATION

(KP2 , 320 MINISAC, LPP at **6°aTDC)**



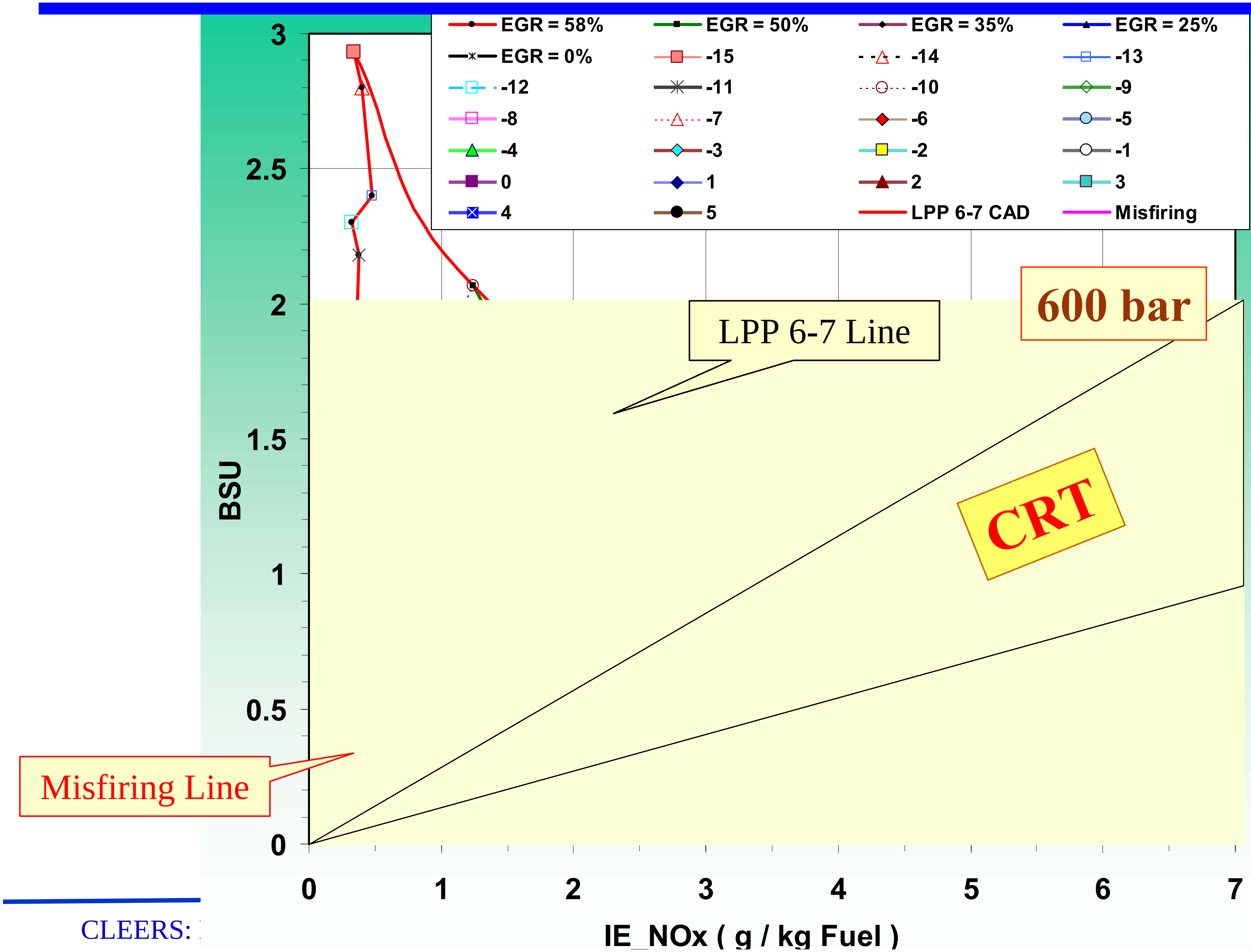
TRADE-OFF Between NOx and HC's, (KP2 , 320 MINISAC)

LPP at 6°aTDC



TRADE-OFF MAP: NOx - BSU, 600 bar

KP2 , 320 MINISAC, SANDRIC CC

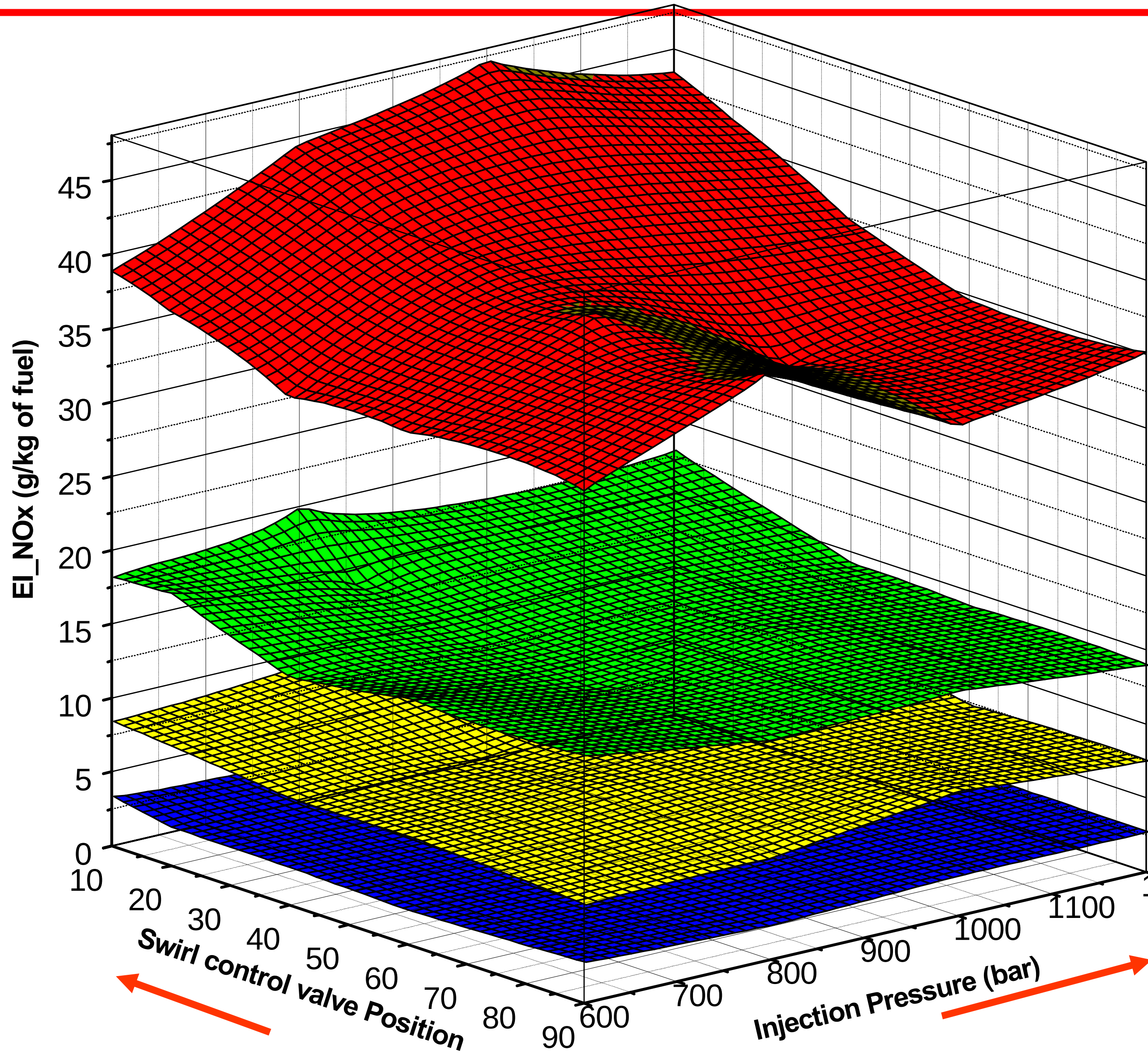


EFFECT OF SWIRL RATIO

ISO-EGR SURFACES for NOx

KP3

MS 320



0%

25%

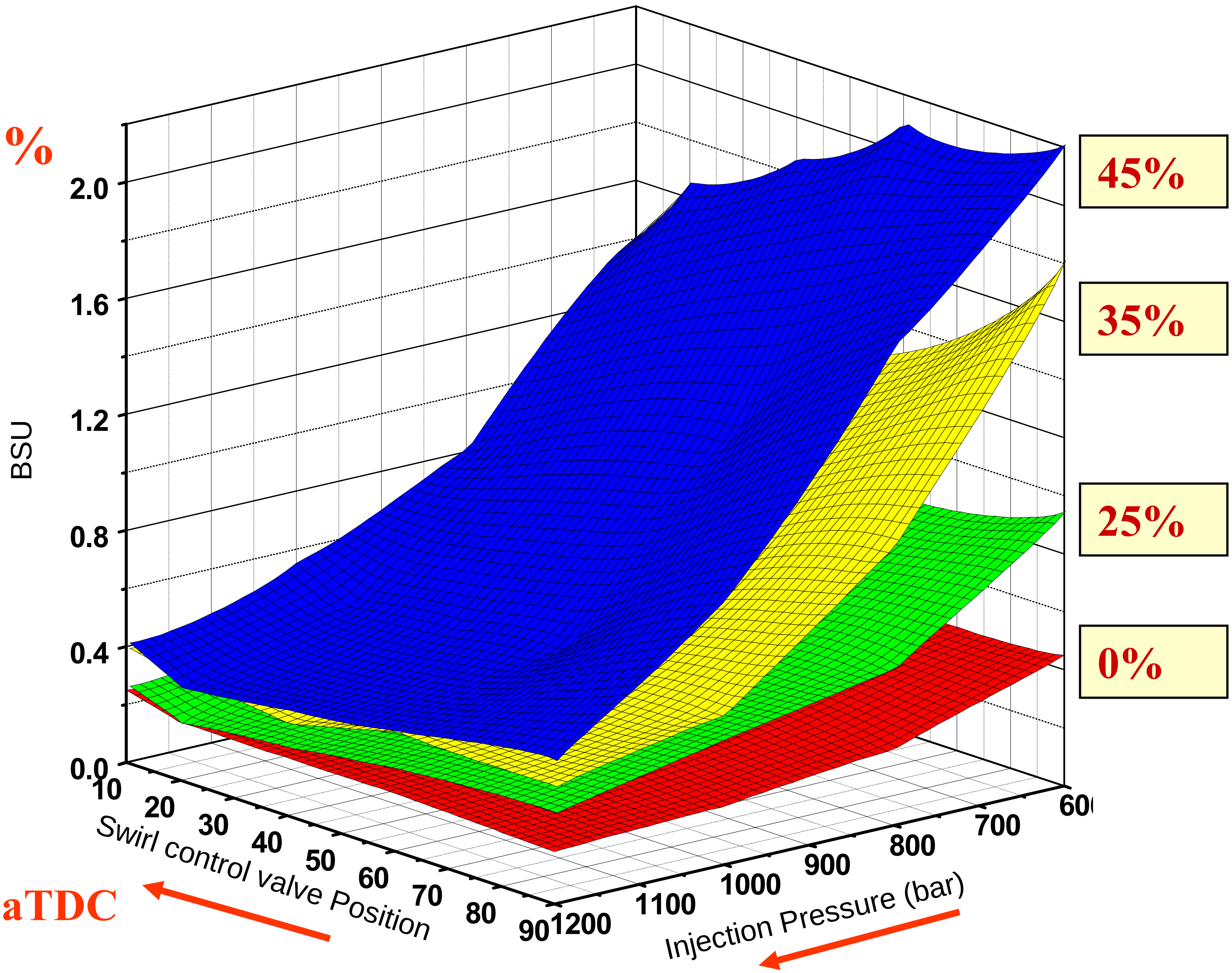
35%

45%

EFFECT of SWIRL &INJECTION PRESSURE on BSU

Ms-320

EGR: 0-45%



KP3

2000 rpm

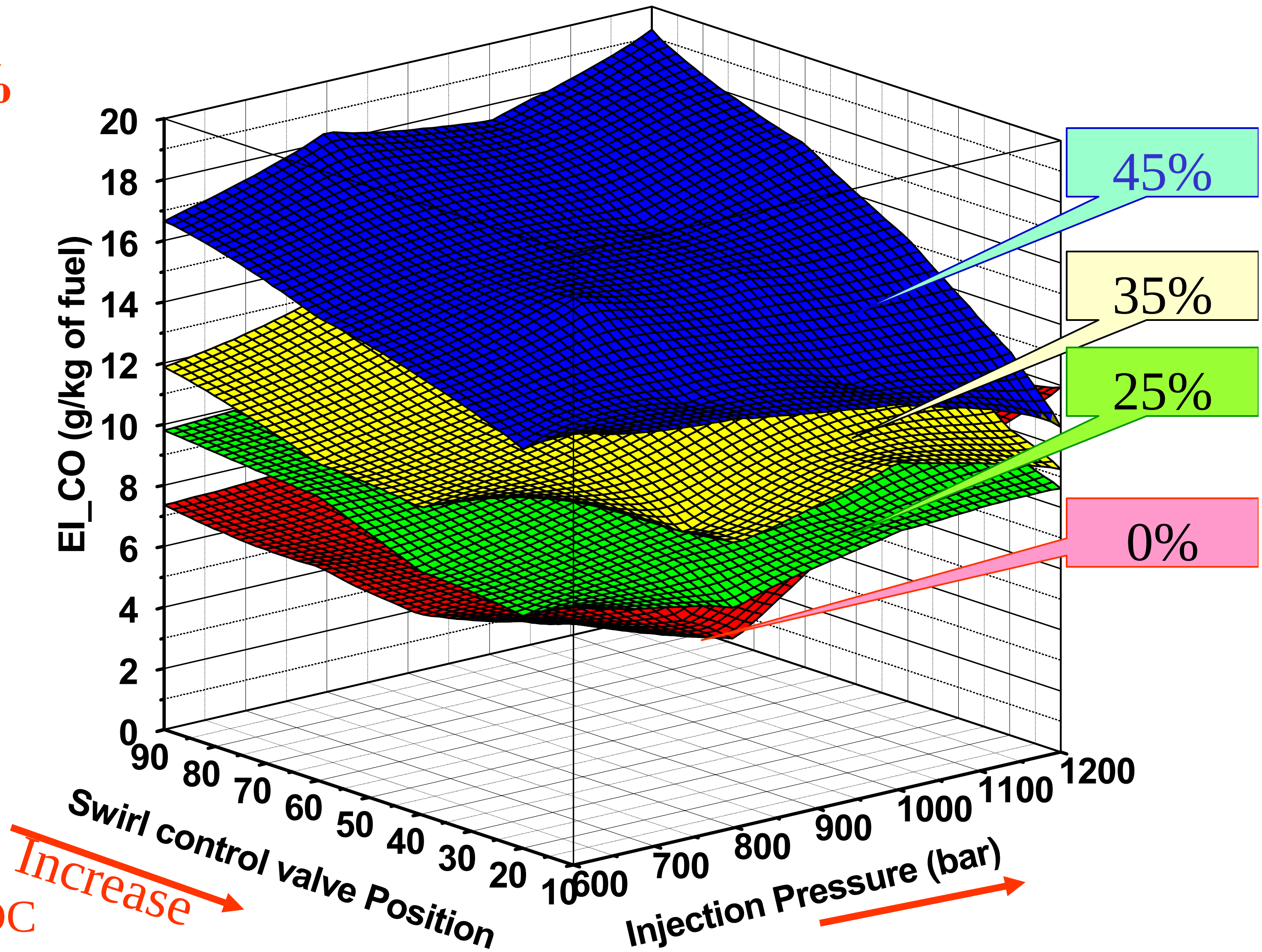
IMEP:5 bar

PPL: 6 –7 °aTDC

EFFECT of SWIRL & INJECTION PRESSURE on CO

MS-320

EGR: 0 %



KP3

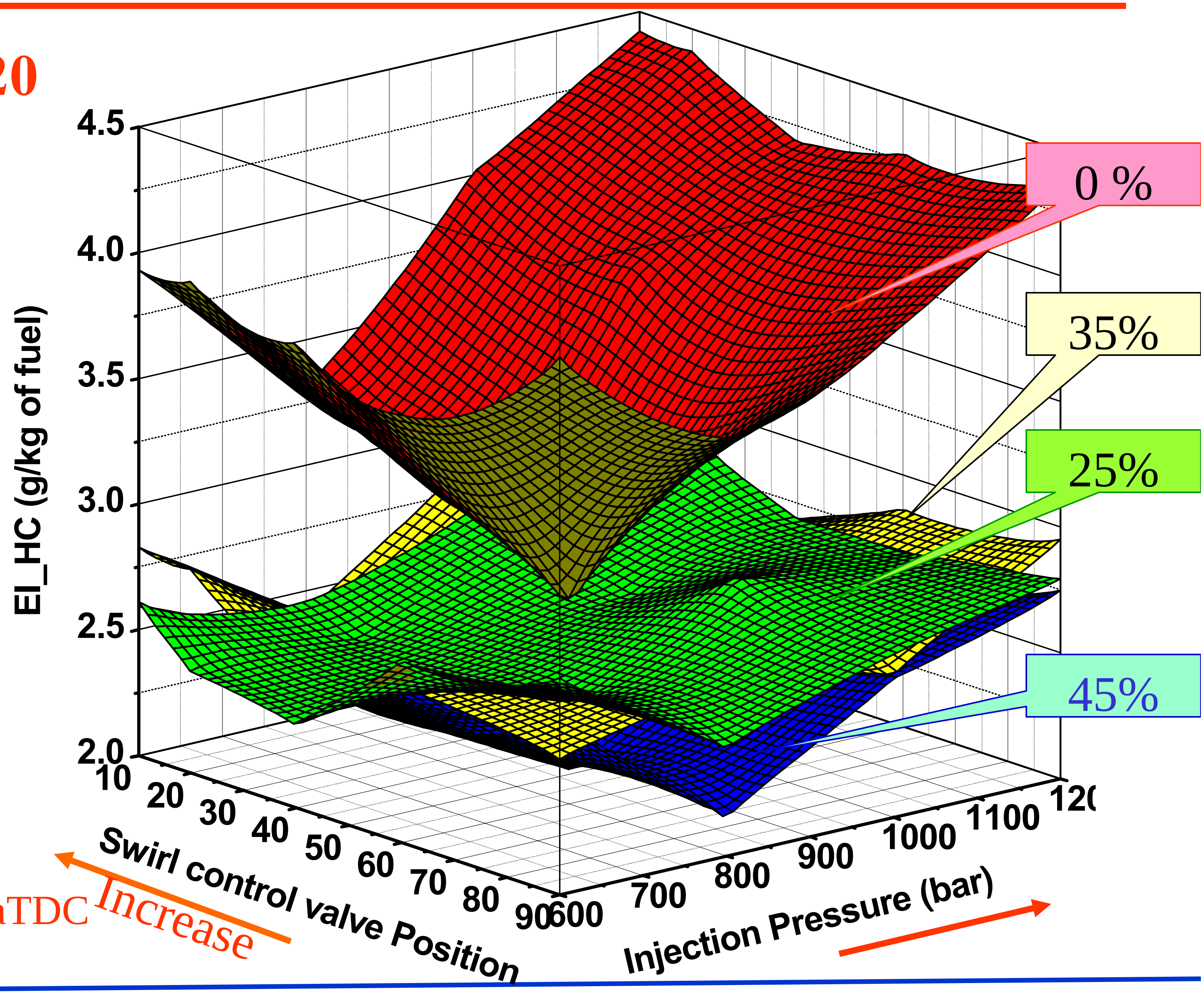
2000 rpm

IMEP:5 bar

PPL: 6 –7 °aTDC

EFFECT of SWIRL & INJECTION PRESSURE on HC

MS-320



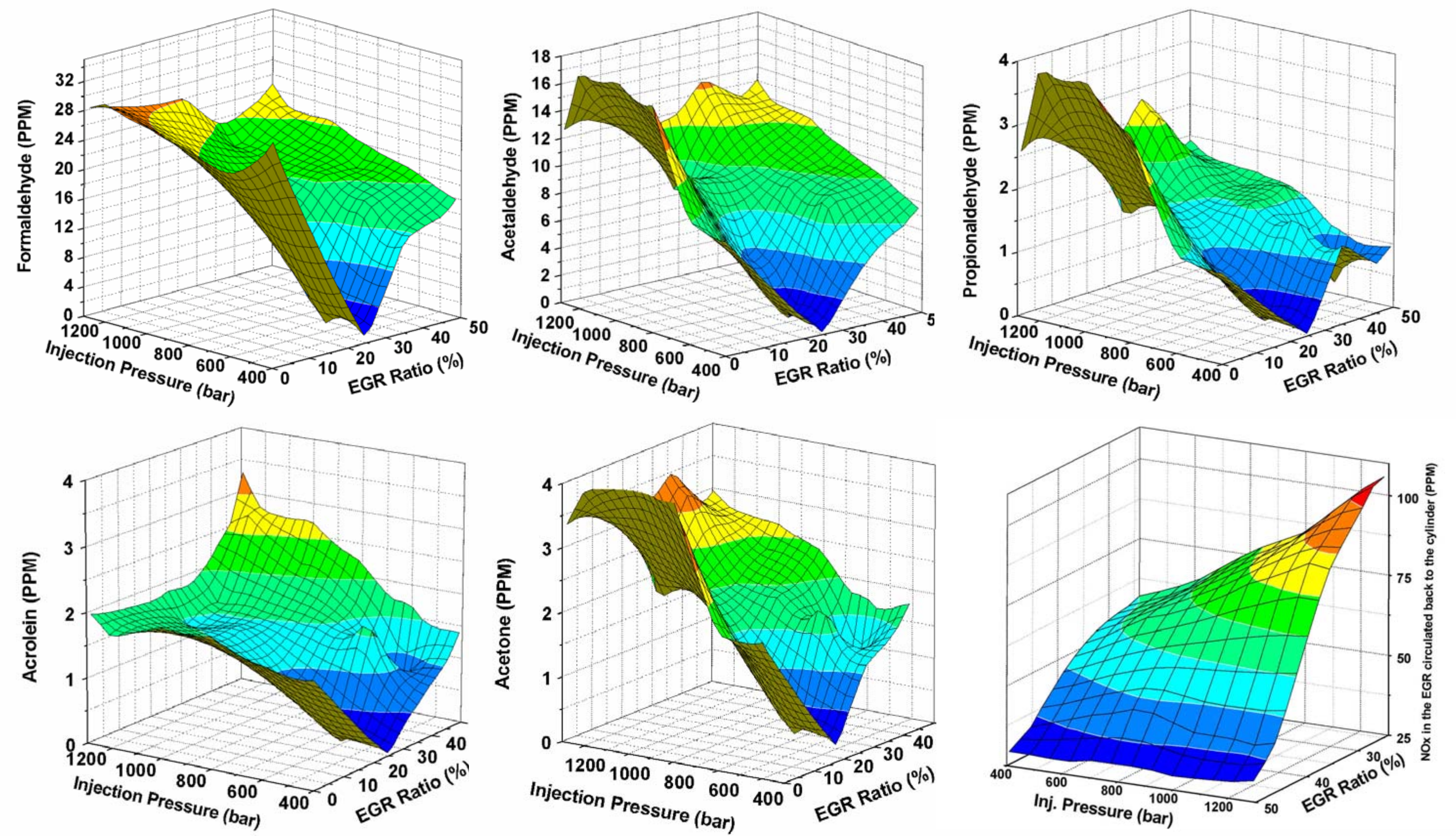
KP3

2000 rpm

IMEP:5 bar

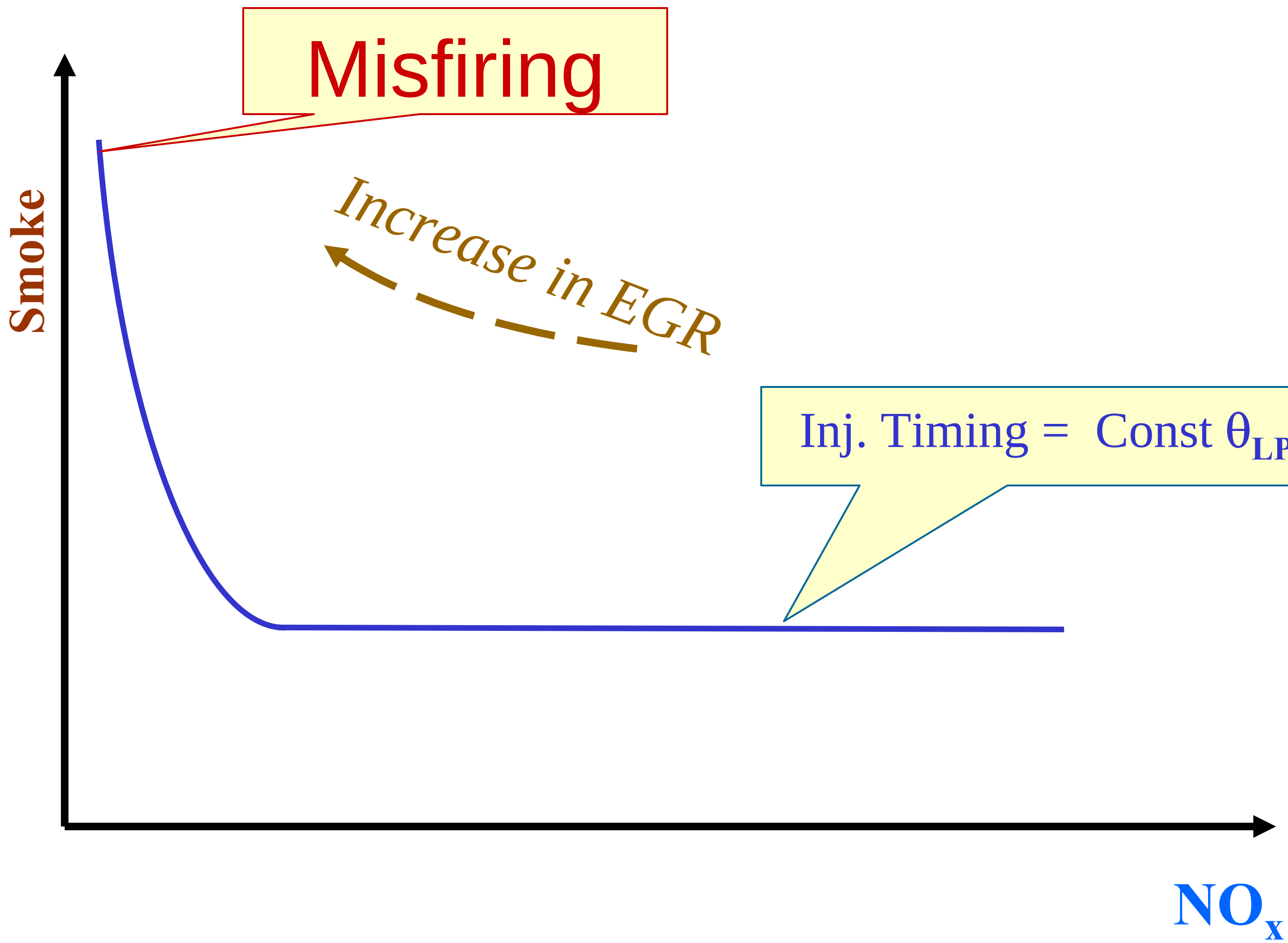
PPL: 6 –7 °aTDC

Aldehydes Emissions

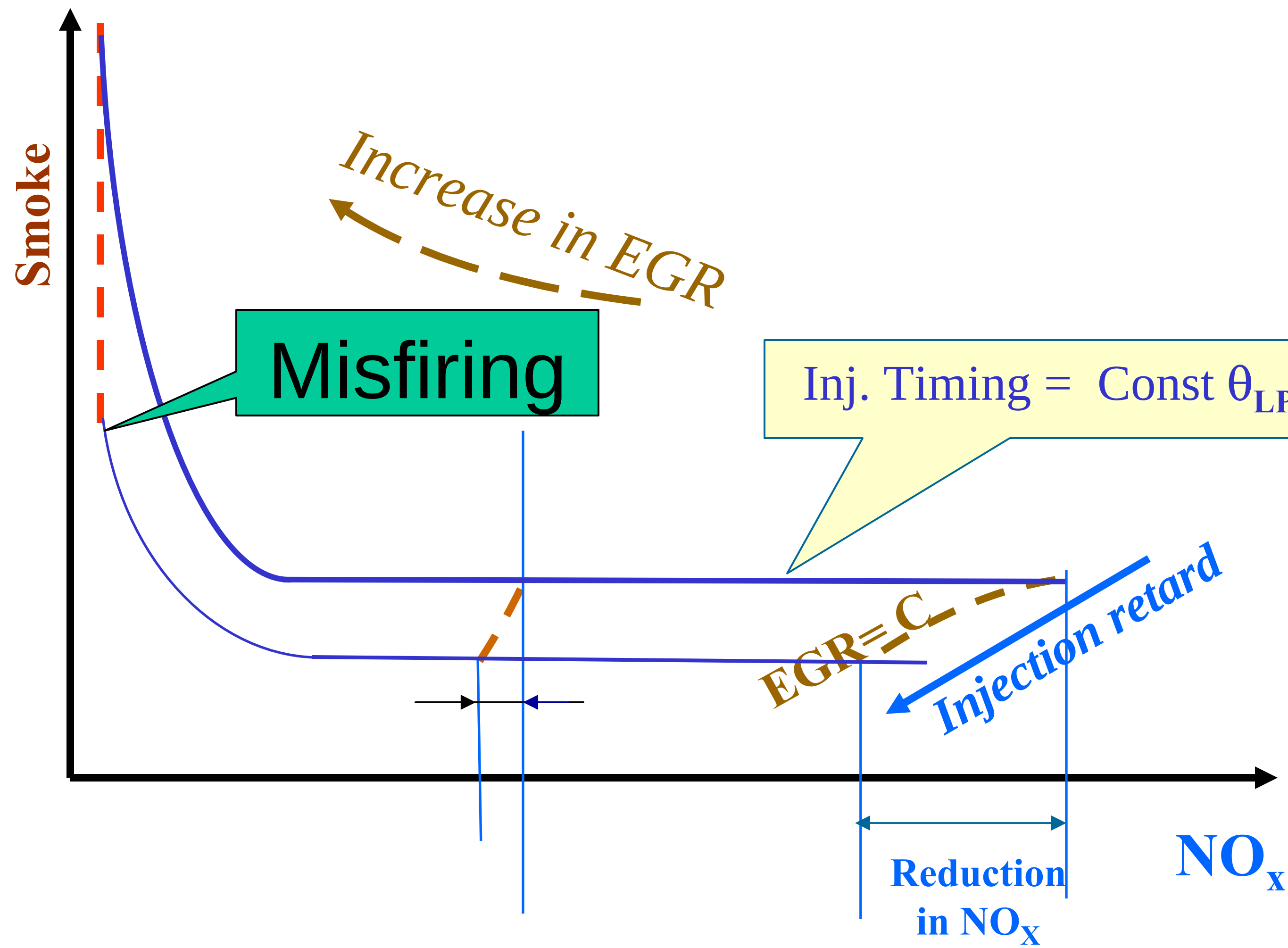


EFFECT OF INJ. TIMING

MAP FOR THE TRADE-OFF BETWEEN NOX & BSU SHOWING ISO TIMING LINES FOR LPP 6-7



DIRECTIONAL MAP FOR THE TRADE-OFF BETWEEN NOX & BSU ISO TIMING AND ISO EGR LINES FOR LPP 6-7 TO ML

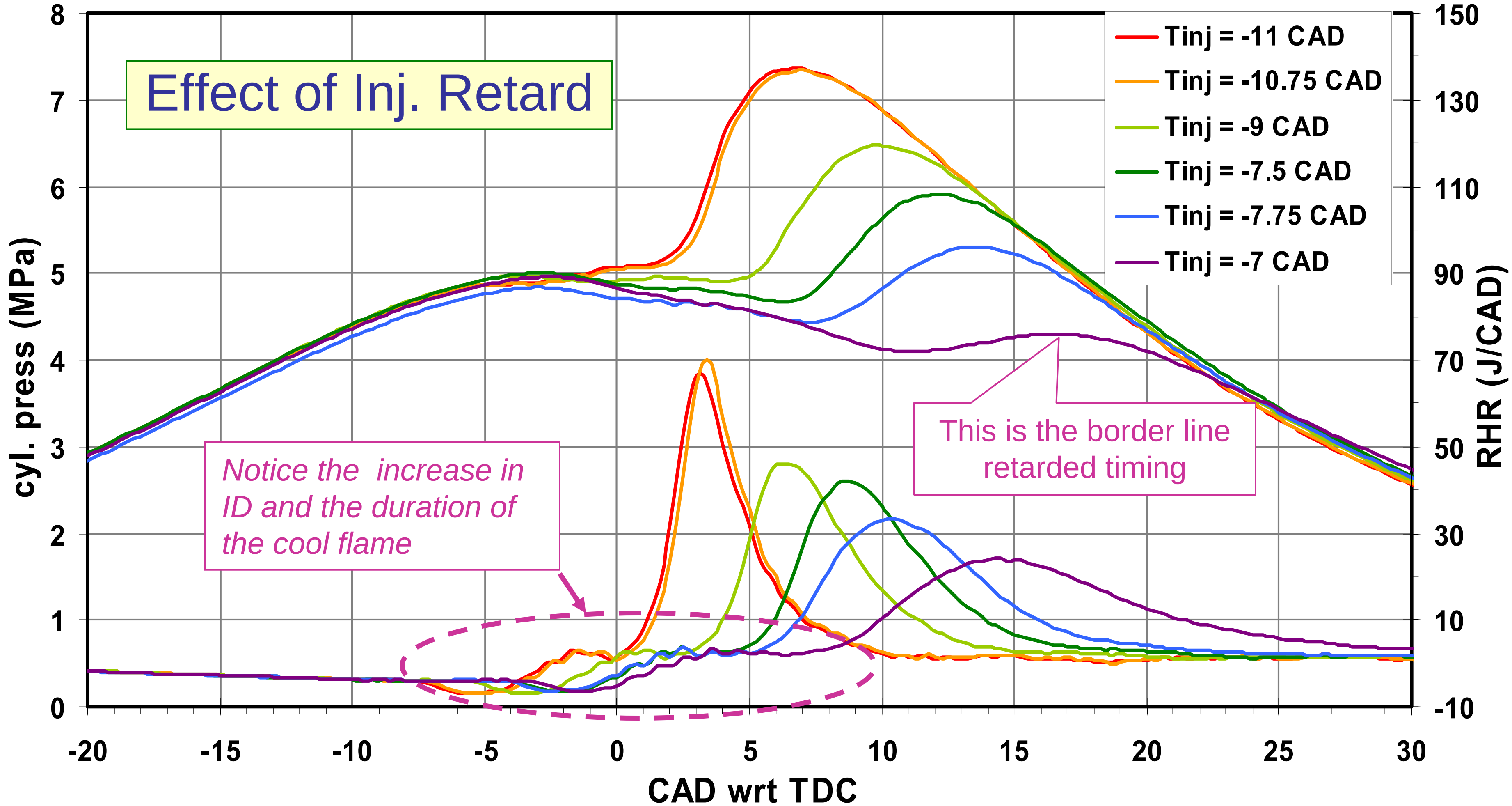


Sample cylinder pressure & RHR traces

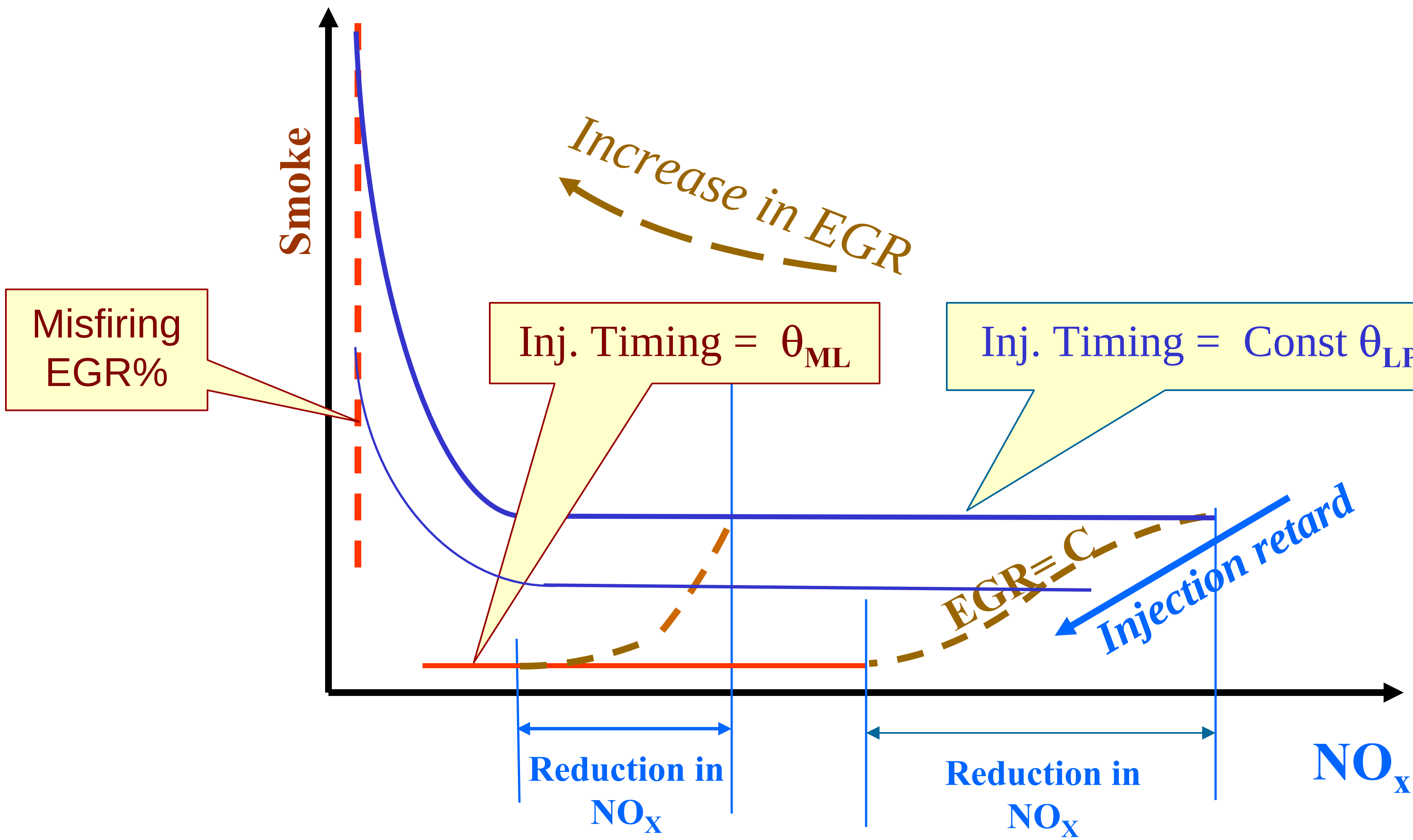
•IMEP = 3 bar
•1500 RPM

Inj Pressure = 800 bar
EGR = 50 %

Inj. Timing = LPPC 3.25°aTDC up to misfire
SR = 7.12

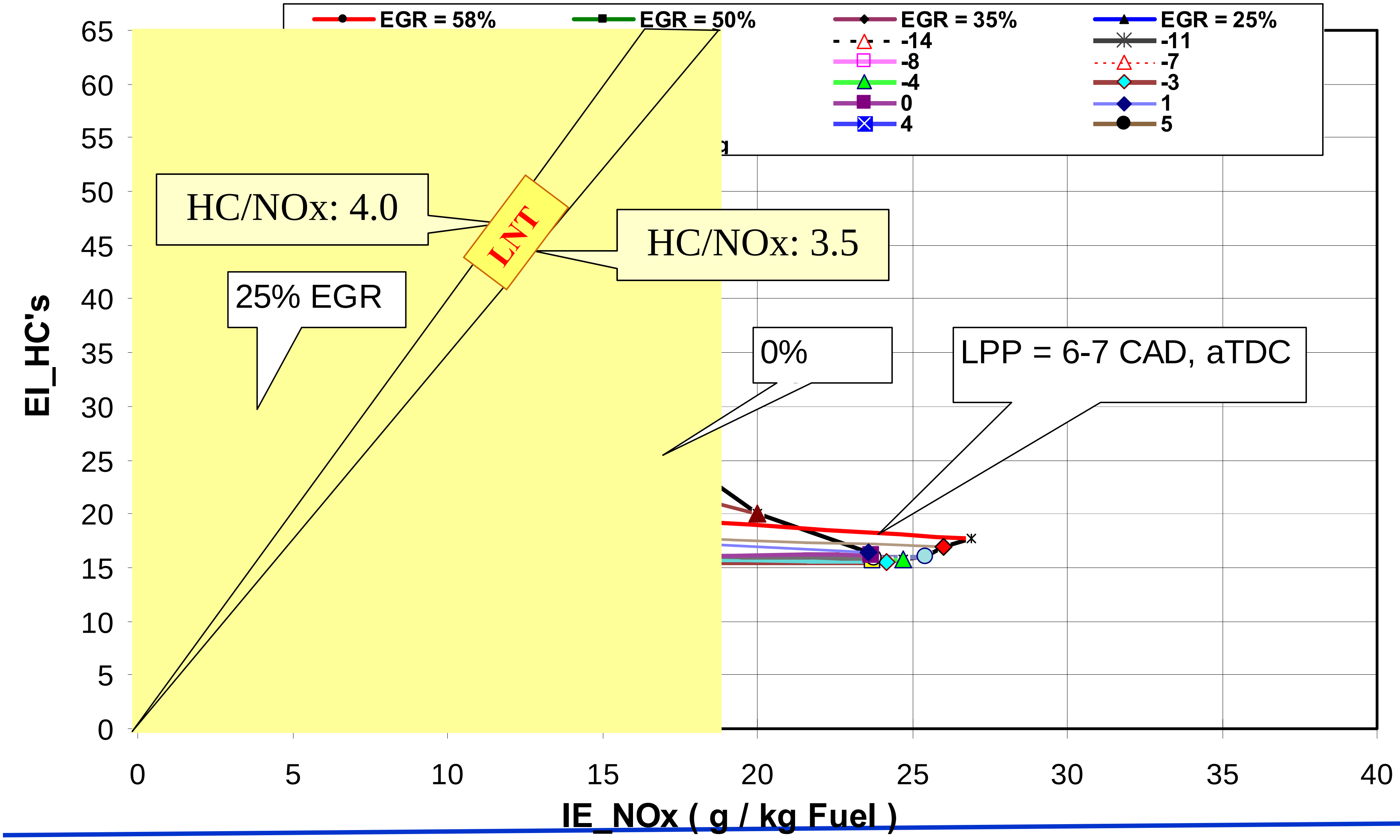


DIRECTIONAL MAP FOR THE TRADE-OFF BETWEEN NOX & BSU ISO TIMING AND ISO EGR LINES FOR LPP 6-7 TO ML



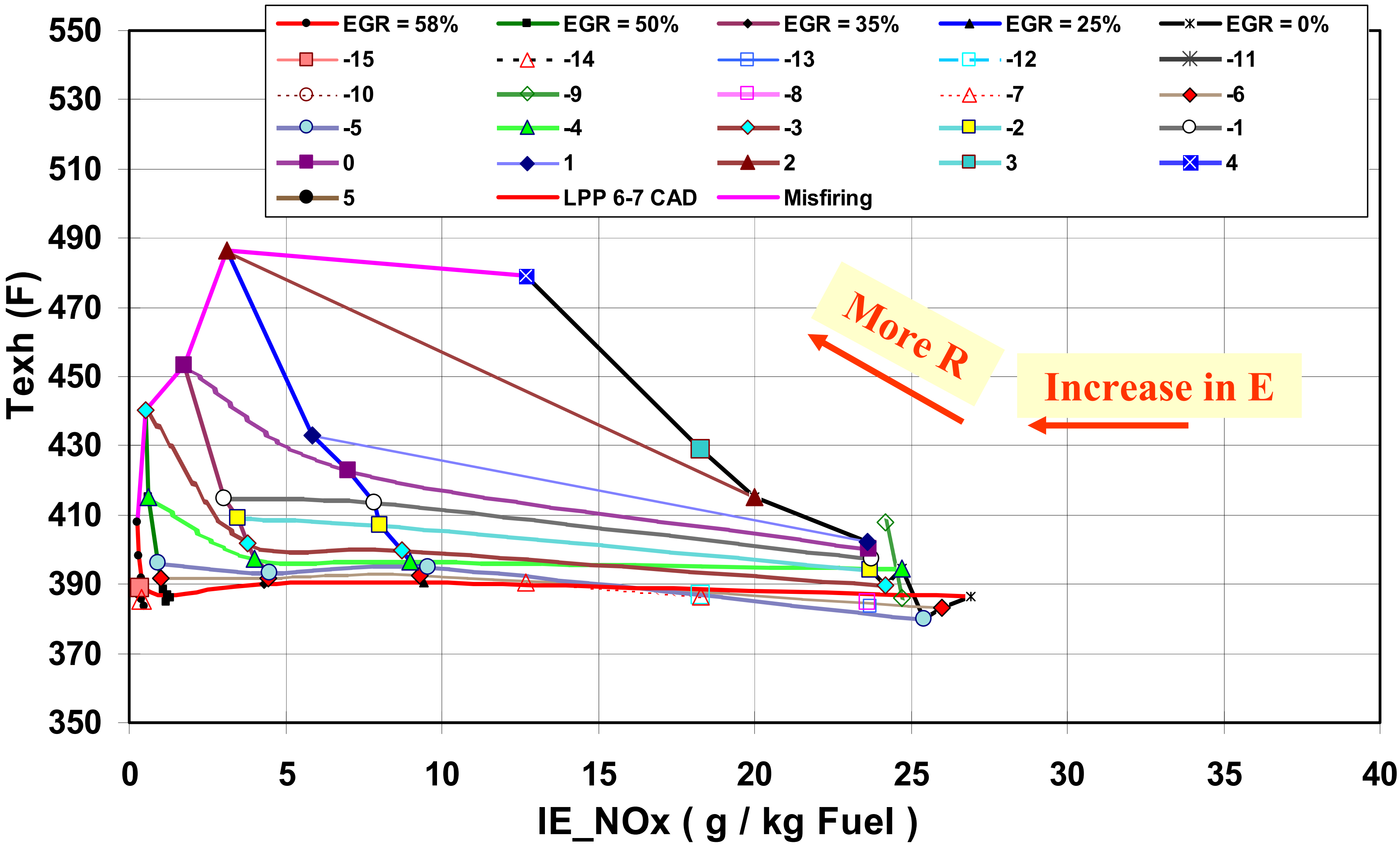
TRADE-OFF Between NOx and HC, 600 bar

Injection timing effect (KP2 , 320 MINISAC)



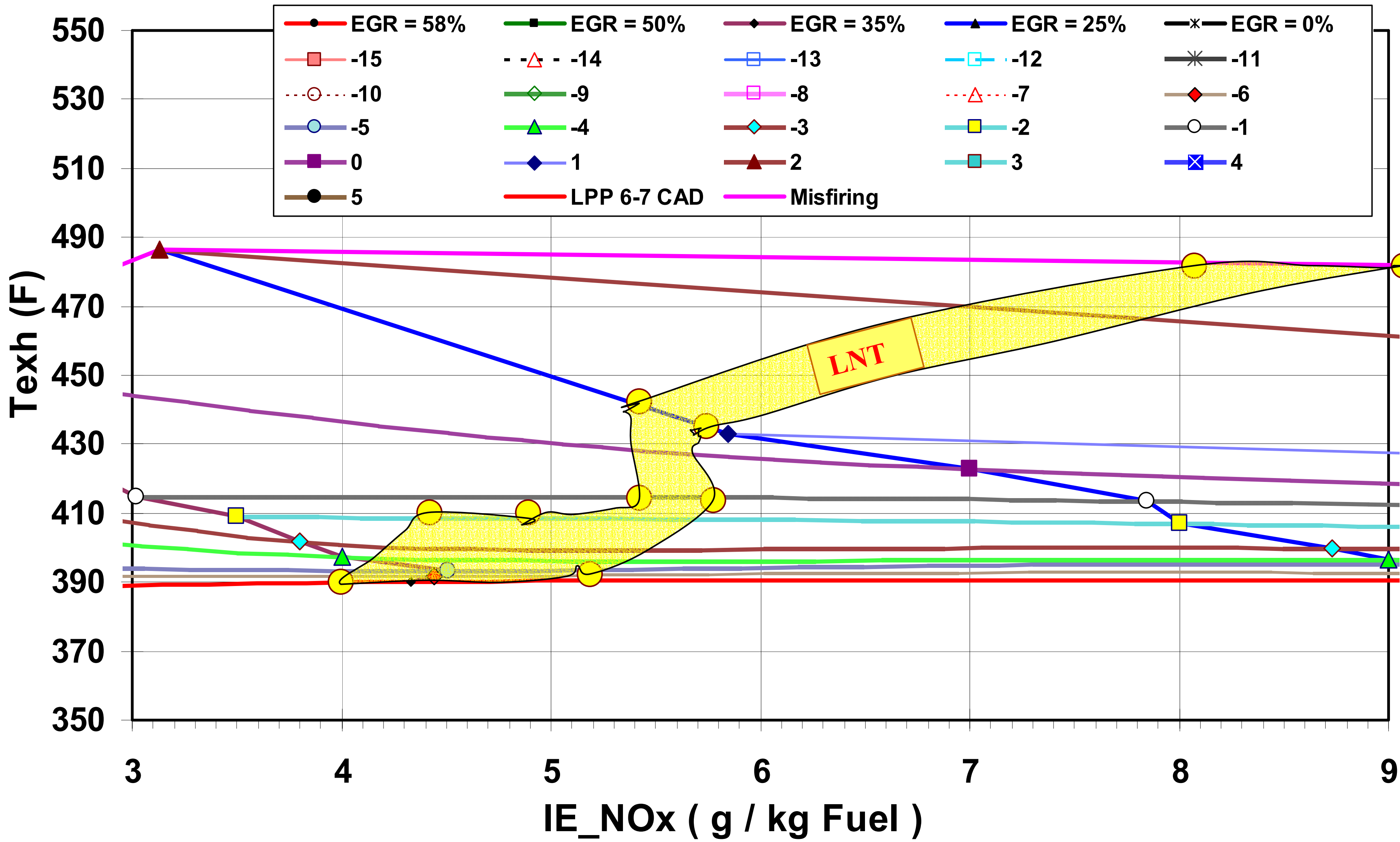
TRADE-OFF Between NOx and Texh (F), 600 bar

Injection timing effect (KP2 , 320 MINISAC)



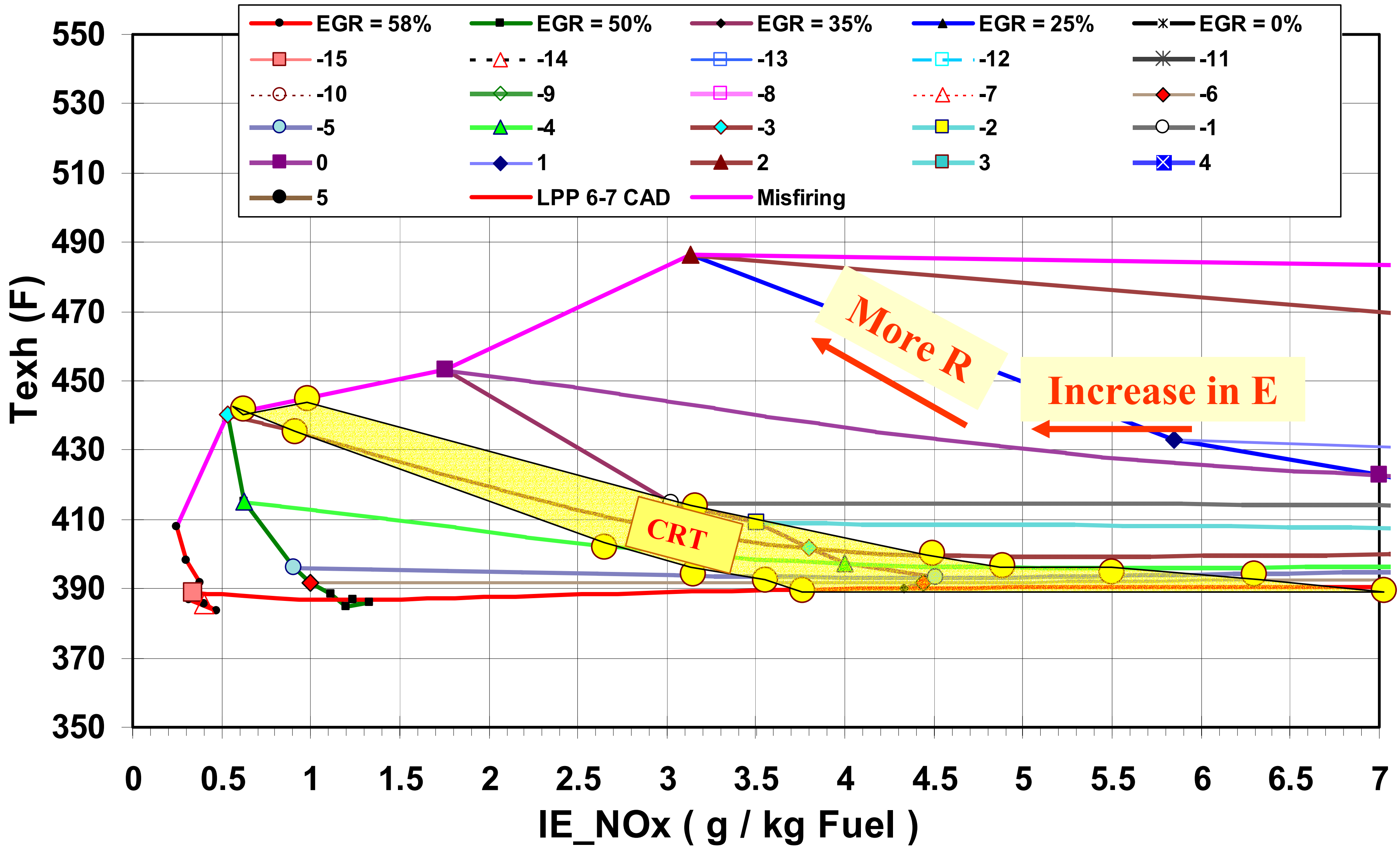
TRADE-OFF Between NOx and Texh (F), 600 bar

Injection timing effect (KP2 , 320 MINISAC)



TRADE-OFF Between NOx and Texh (F), 600 bar

Injection timing effect (KP2 , 320 MINISAC)

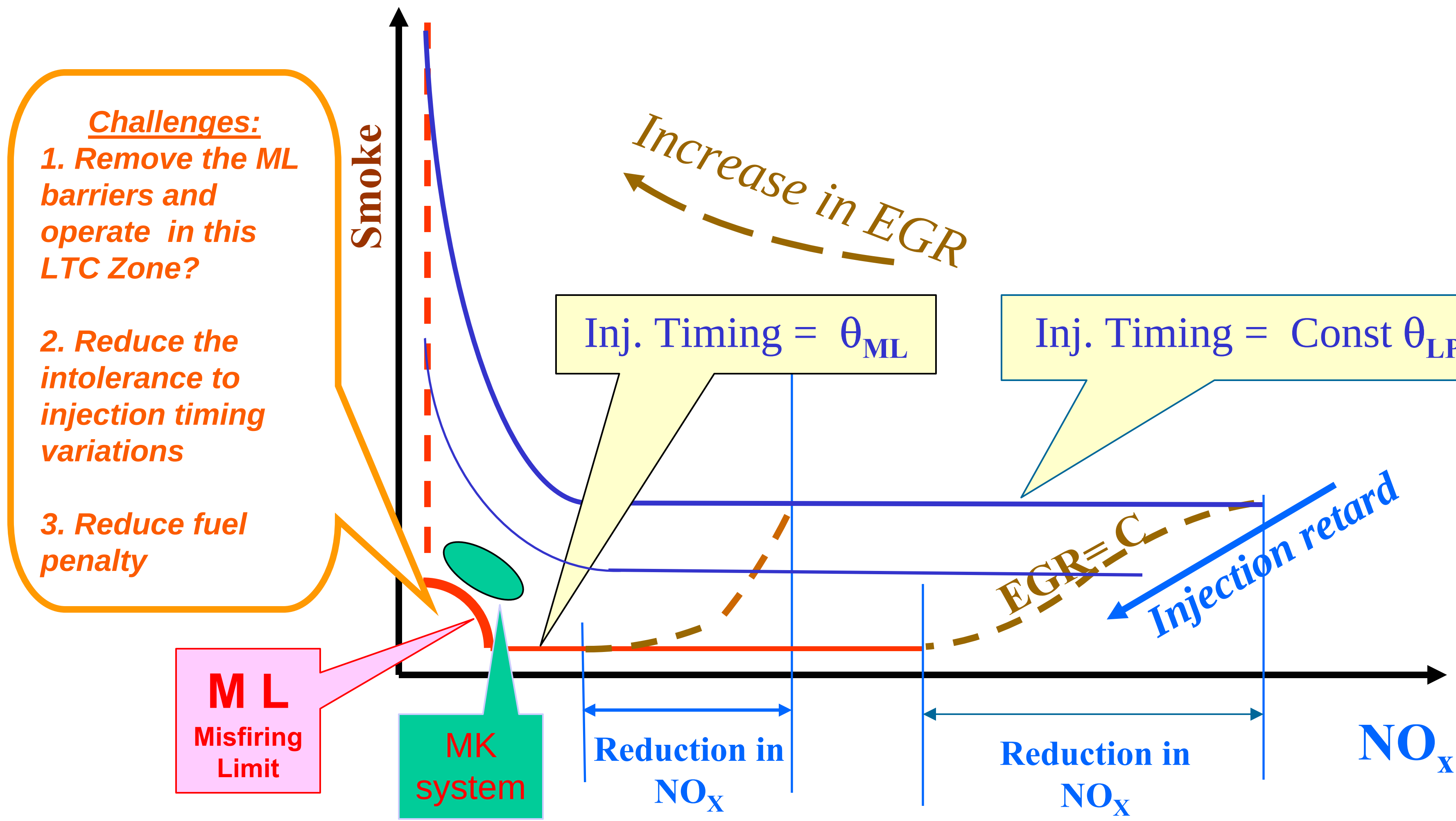


LTC REGIMES

MK Strategy

- P: Medium injection pressures
- E: High close to misfiring
- Inj. Timing: Retarded close to misfiring
- S: Very high

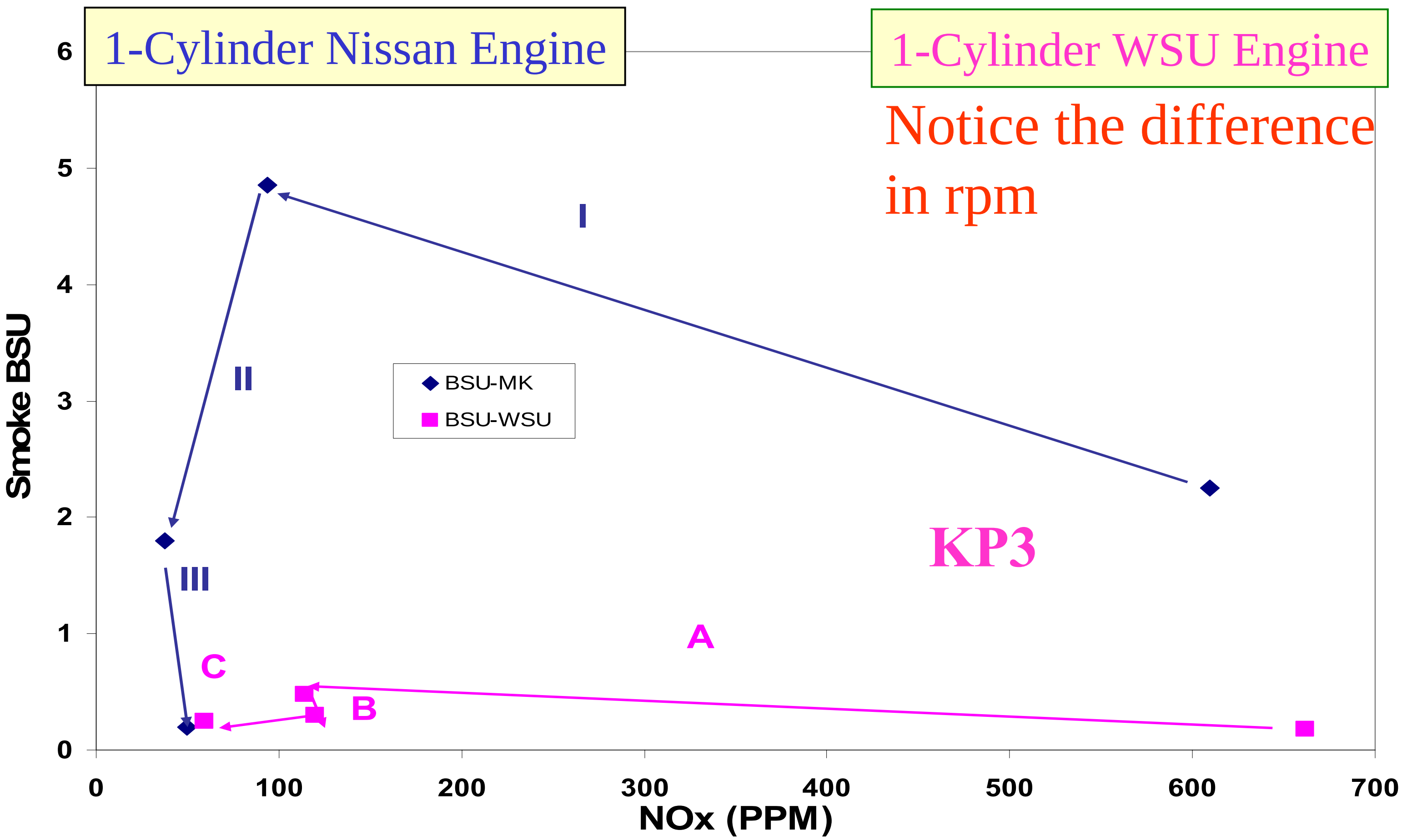
DIRECTIONAL MAP FOR THE TRADE-OFF BETWEEN NOX & BSU ISO TIMING AND ISO EGR LINES FOR LPP 6-7 TO ML



COMPARISON BETWEEN WSU AND MK ENGINES NOx-BSU TRADE-OFF

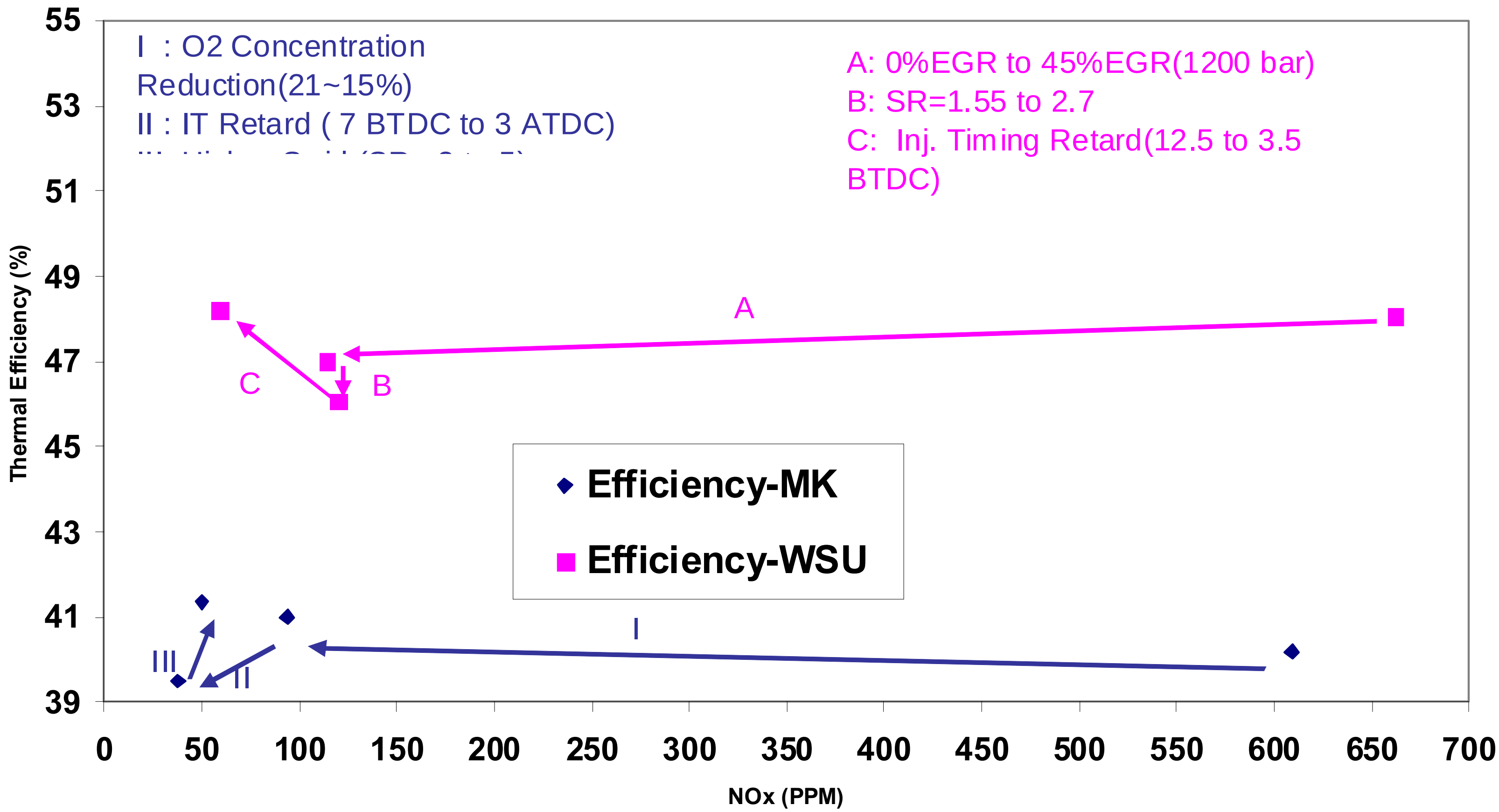
1400 rpm, Qf=20mm^3
I : O2 Concentration Reduction(21~15%)
II : IT Retard (7 BTDC to 3 ATDC)
III: Higher Swirl (SR= 3 to 5)

2000 rpm, Qf=19.9 mm^3
A: 0%EGR to 45%EGR O_2=15.5% (1200 bar)
B: SR=1.55 to 2.7
C: Inj. Timing Retard(12.5 to 3.5 BTDC)



COMPARISON BETWEEN WSU AND MK ENGINES
NOx-BSU TRADE-OFF

MK: 1400 rpm, Qf=20.0 mm^3
WSU: 2000 rpm, Qf=19.9 mm^3



LTC - WSU

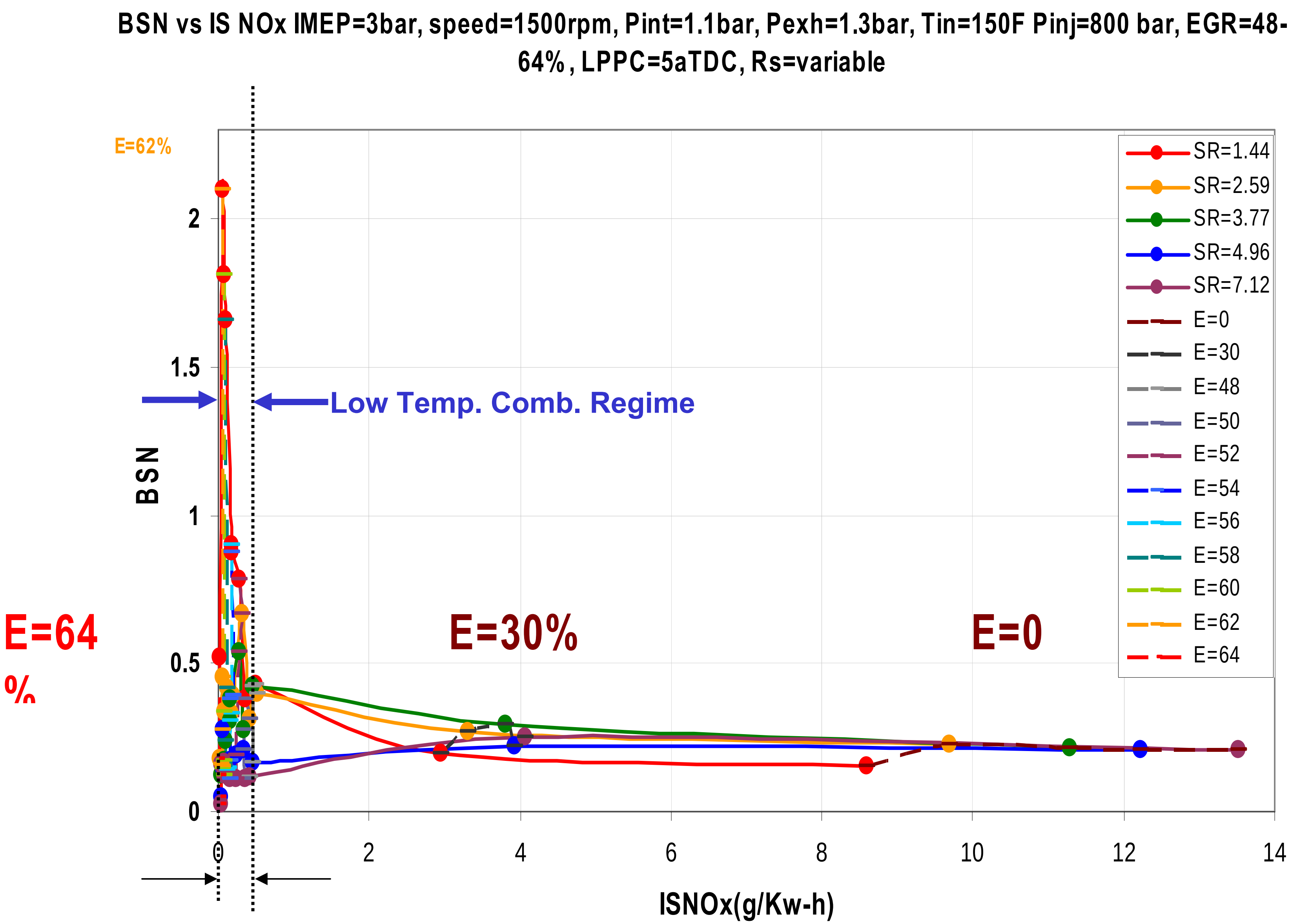
WSU (LTC)

Optimum Strategy

- P: High
- E: High but far from misfiring
- Inj. Timing: Advanced
- S: Optimum

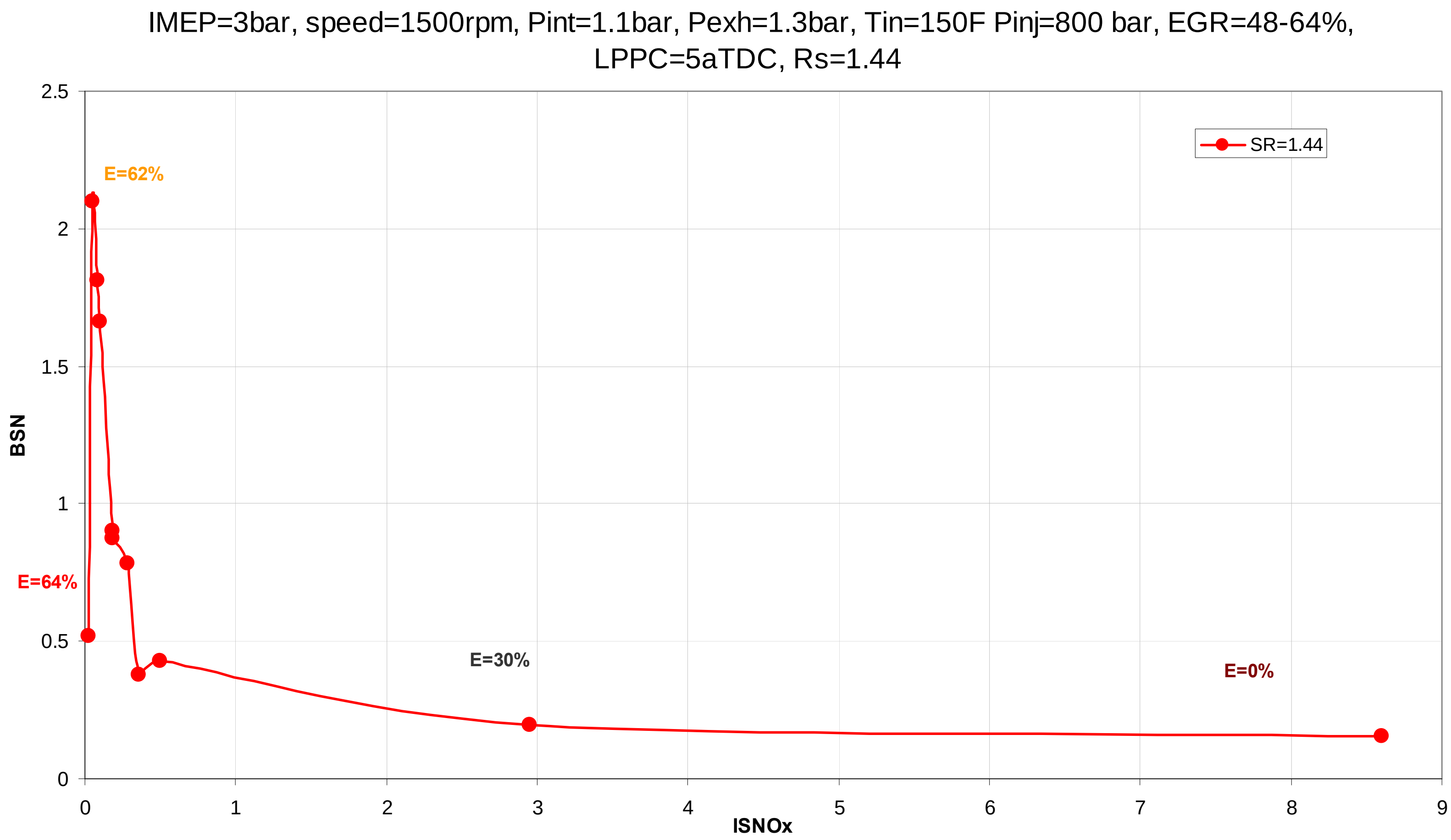
EFFECT OF EGR%
ON ISFC and IS-EMISSIONS

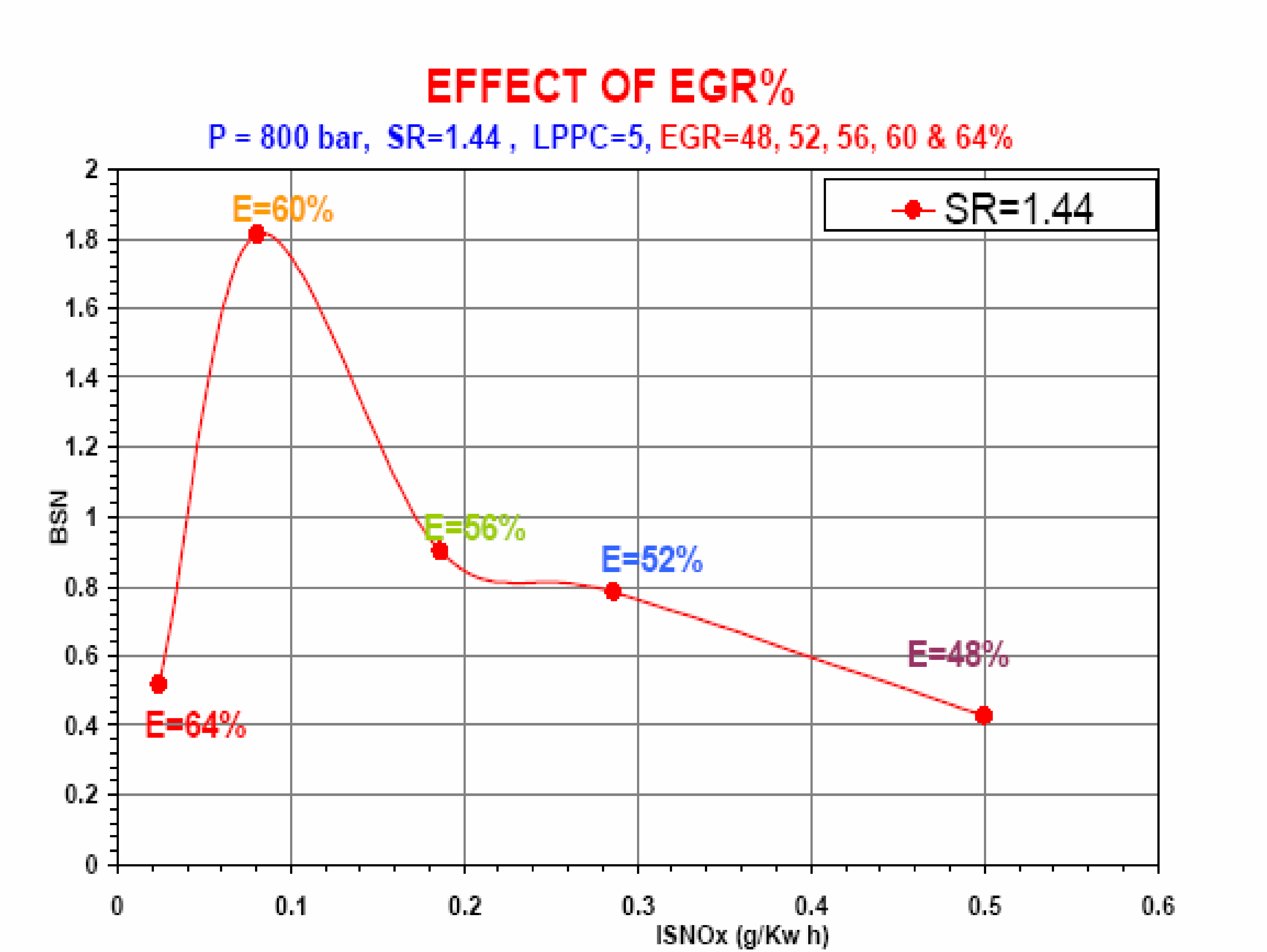
P: 800 Bar, LPPC = 5°aTDC, SR= 1.44



BSN vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64% , LPPC=5aTDC, Rs=variable
E=62%
BSN
ISNOx(g/Kw-h)
Low Temp. Comb. Regime
E=64 %
E=30%
E=0
SR=1.44
SR=2.59
SR=3.77
SR=4.96
SR=7.12
E=0
E=30
E=48
E=50
E=52
E=54
E=56
E=58
E=60
E=62
E=64

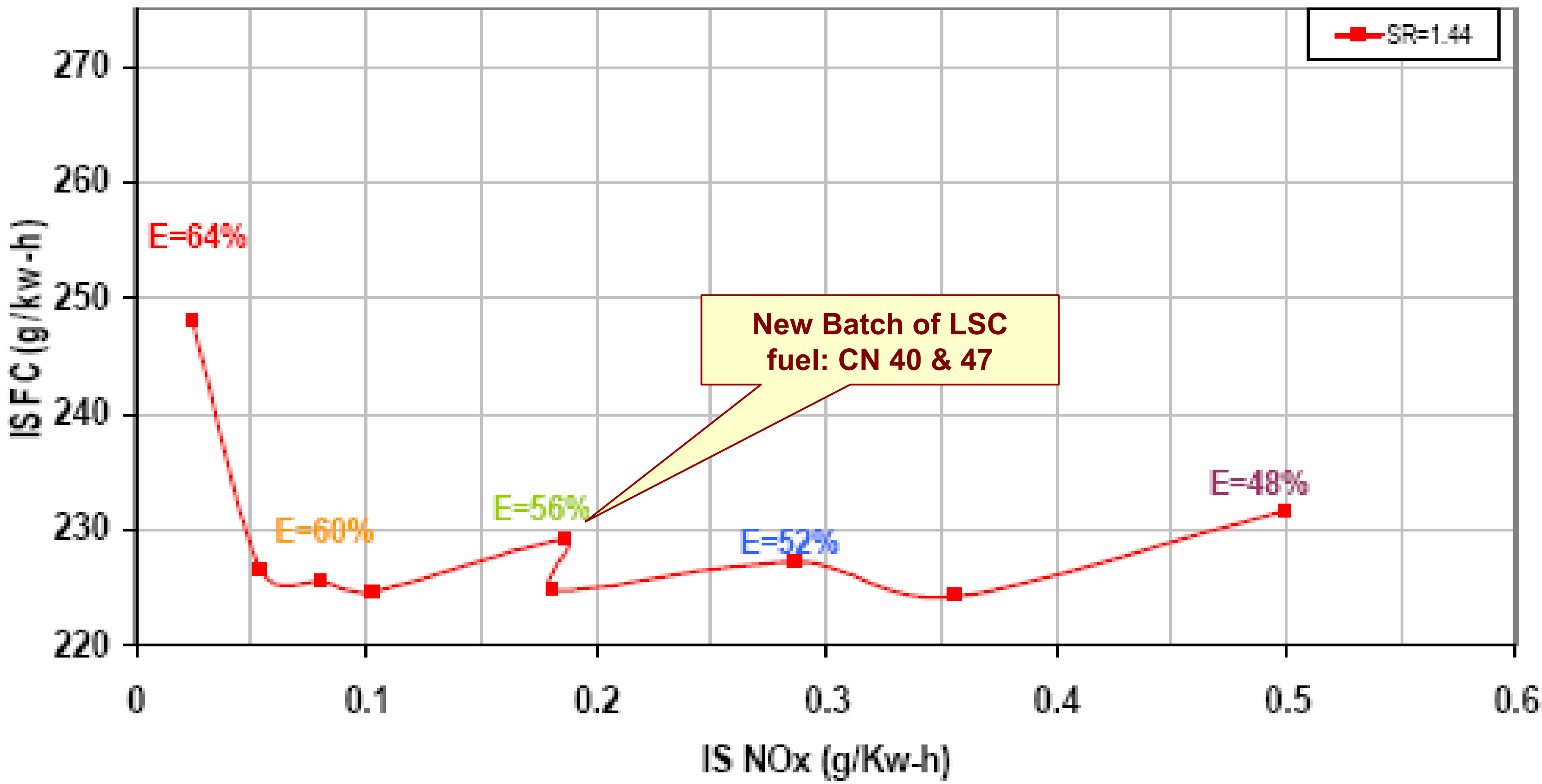
Trade-Off between NOx and BSU EGR: 0 to misfiring limit




EFFECT OF EGR%
P = 800 bar, SR=1.44 , LPPC=5, EGR=48, 52, 56, 60 & 64%
SR=1.44
E=60%
E=56%
E=52%
E=48%
E=64%
BSN
ISNOx (g/Kw h)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6

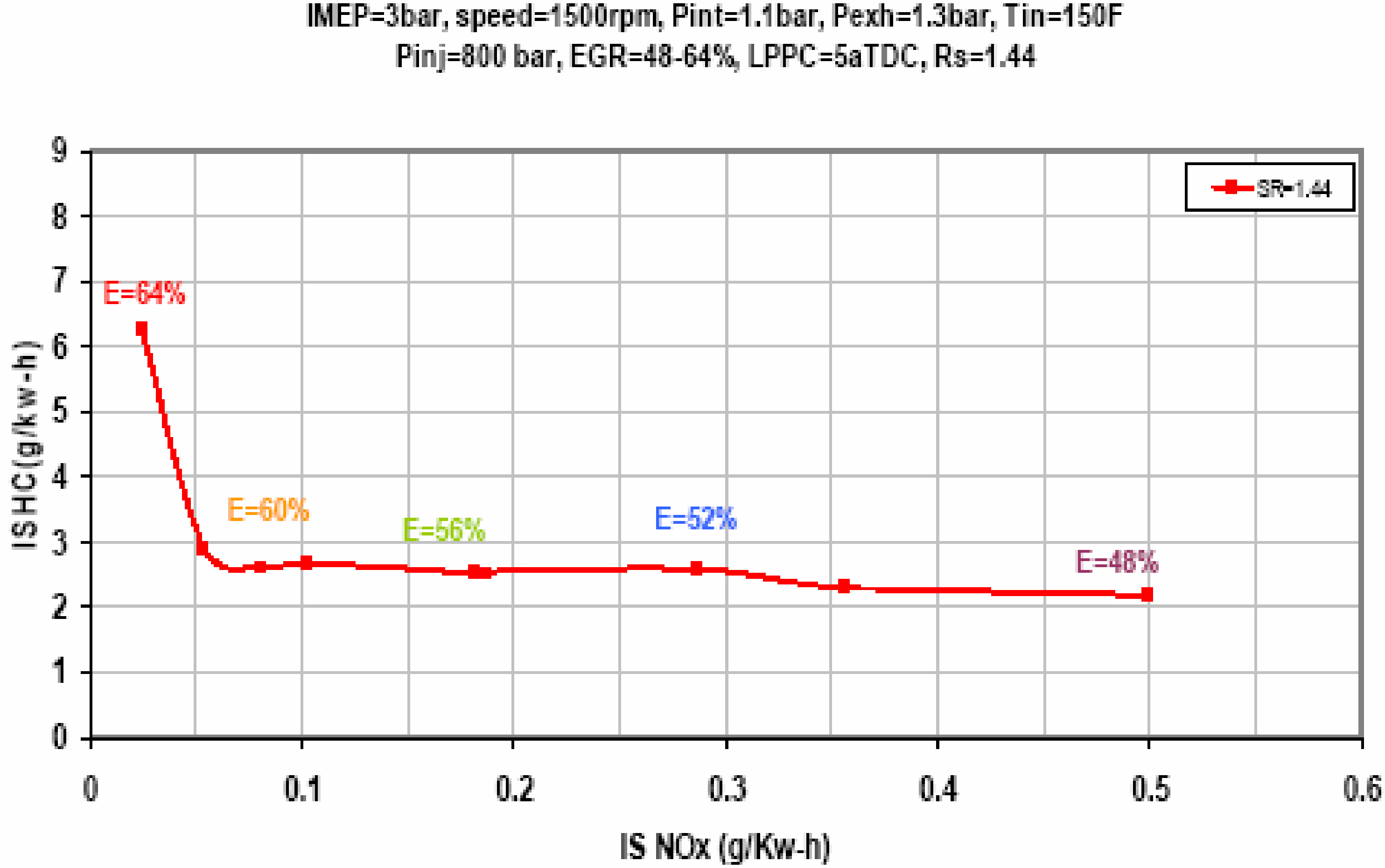
TRADE-OFF BETWEEN ISNO$_x$ AND ISFC
EFFECT OF EGR

P: 800 bar, E: 48%, to 64%, LPPC: 5°aTDC, SR:1.44

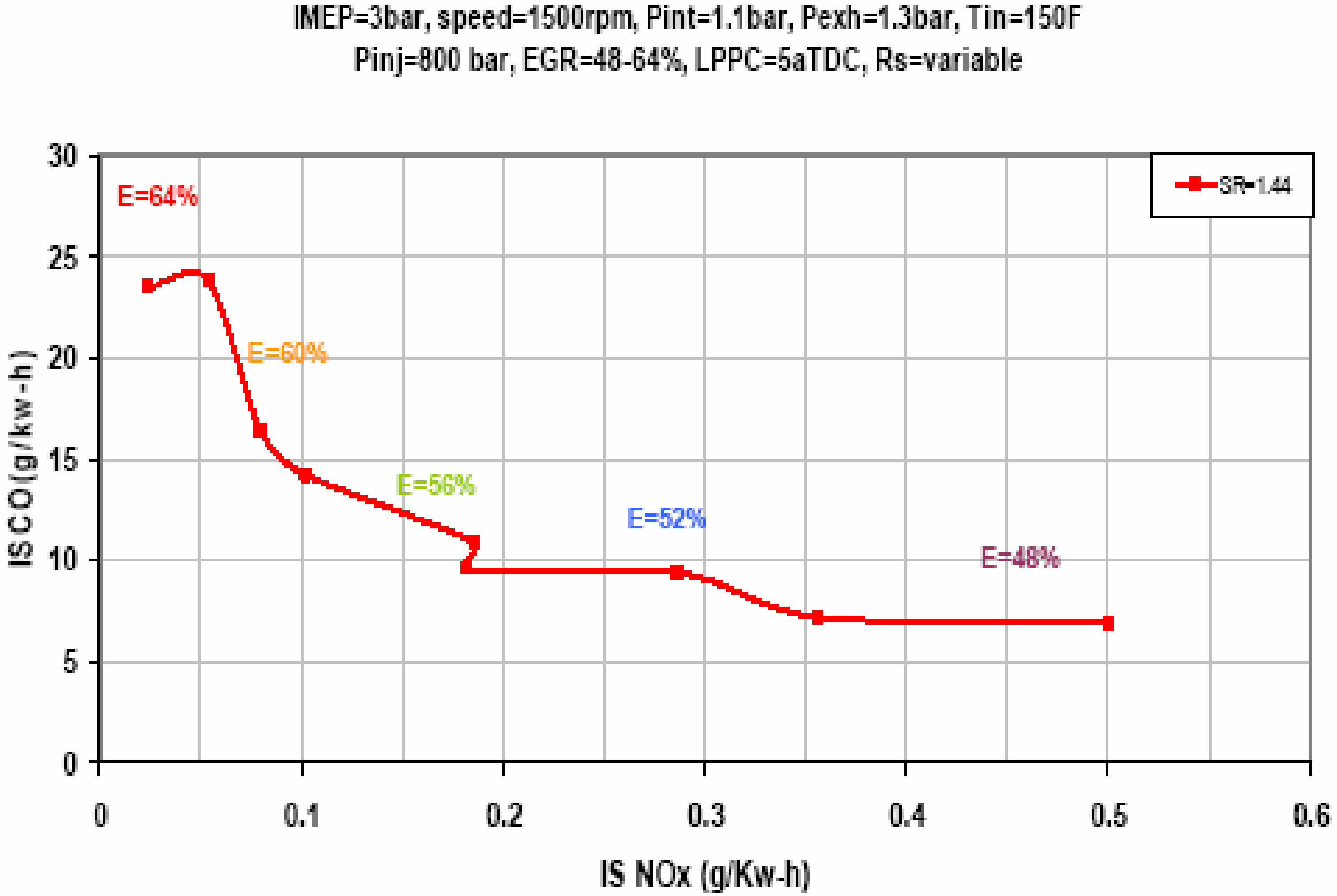


TRADE-OFF BETWEEN ISNO$_X$ AND ISHC EFFECT OF EGR

P: 800 bar, E: 48%, to 64%, LPPC: 5°aTDC, SR:1.44



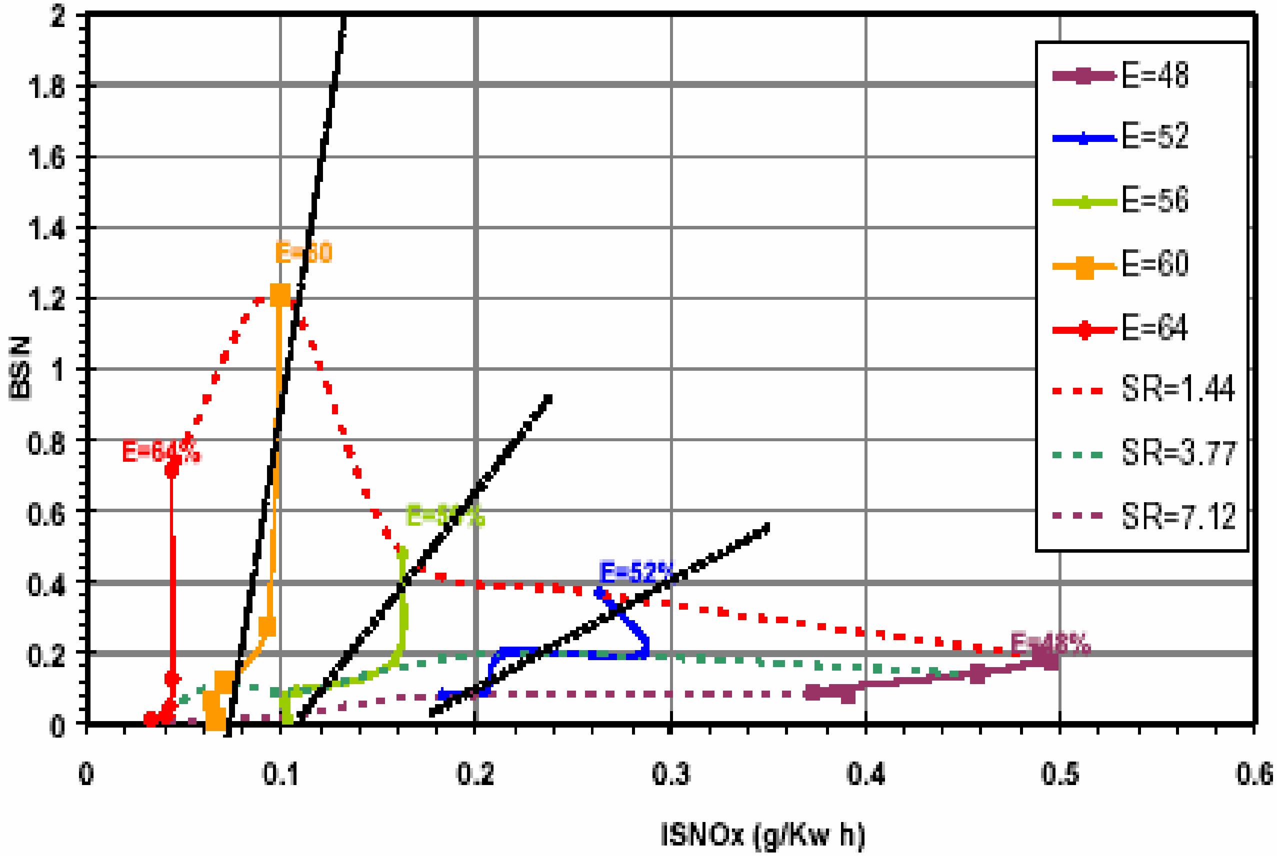
P: 800 bar, E: 48%, to 64%, LPPC: 5°aTDC, SR:1.44



EFFECT OF SWIRL RATIO AT DIFFERENT IMJECTION PRESSURES

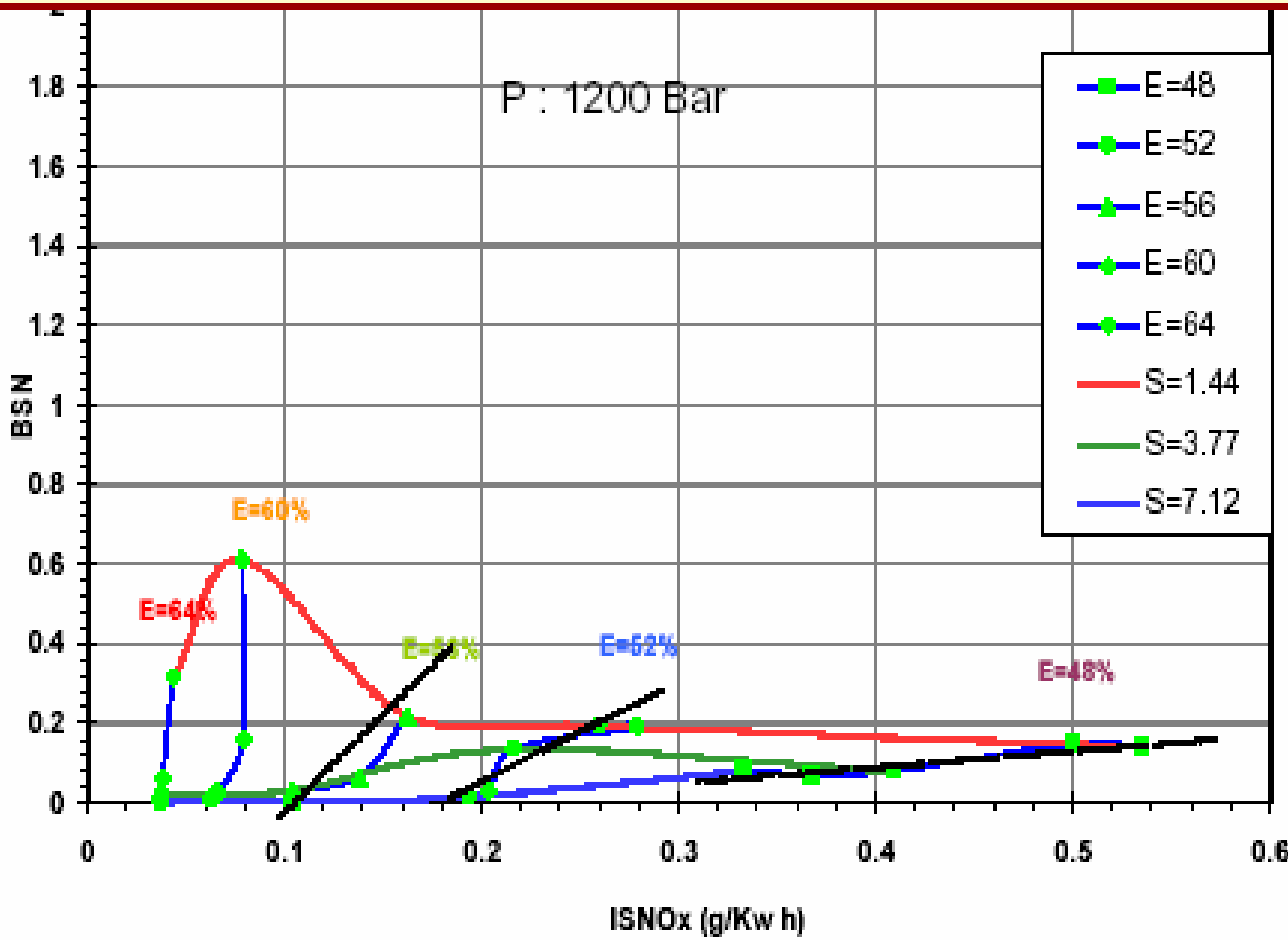
TRADE-OFF MAP FOR NO_x and BSU

P = 1000 bar, SR=1.44- 7.12 , LPPC=5, EGR=48, 52, 56, 60 & 64%

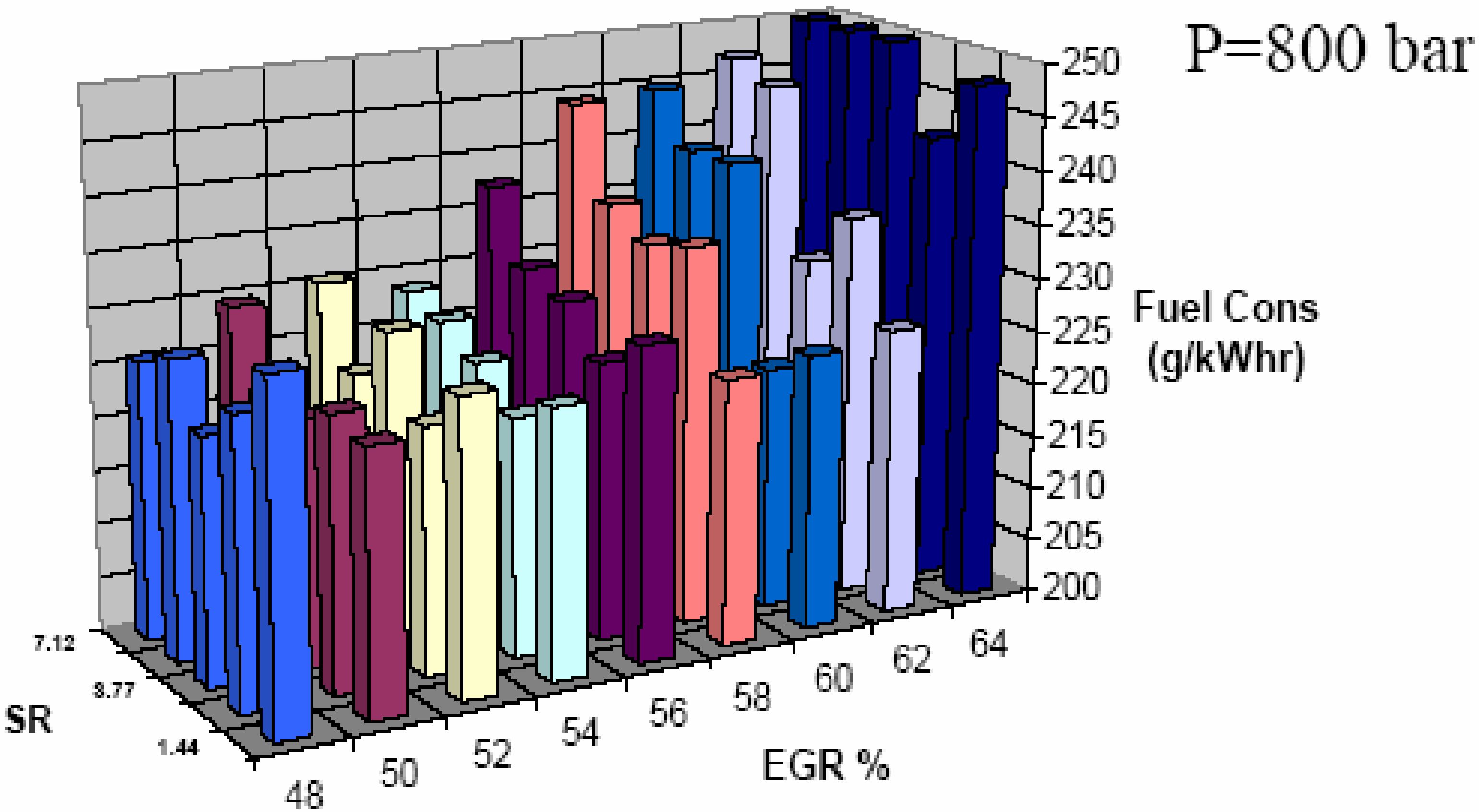


TRADE-OFF MAP FOR NO_x and BSU

P = 1200 bar, SR=1.44- 7.12 , LPPC=5, EGR=48, 52, 56, 60 & 64%



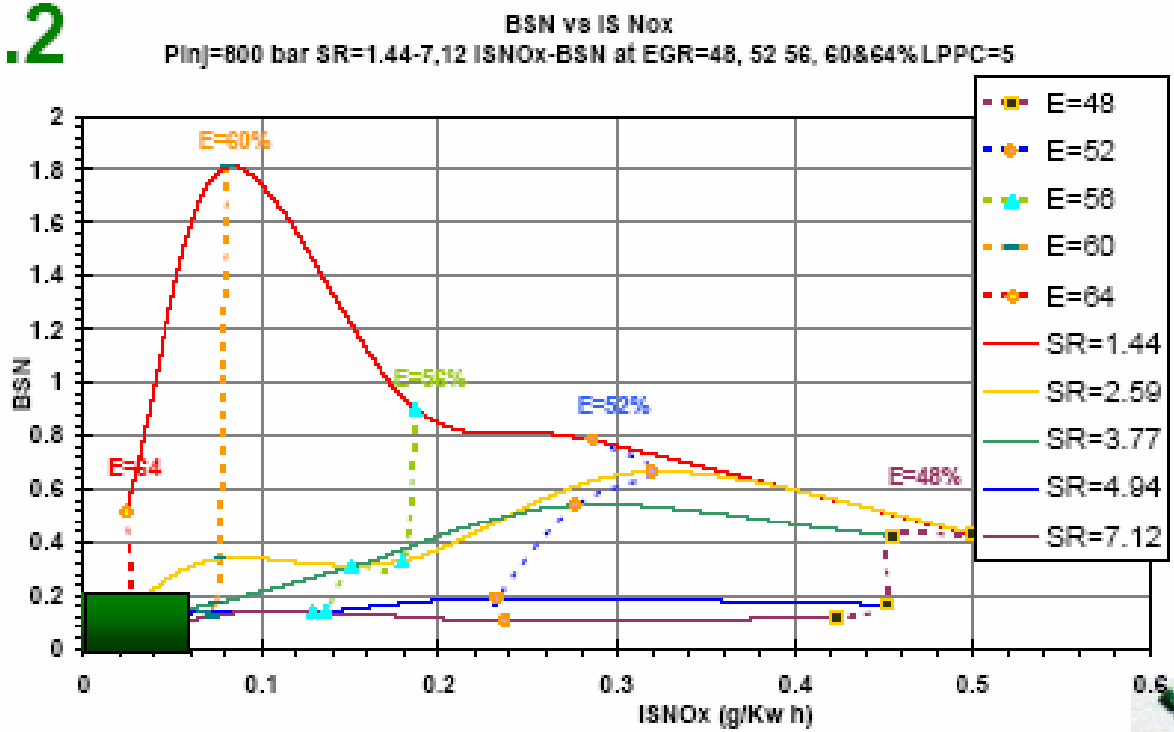
EFFECT OF EGR AND SR ON ISFC

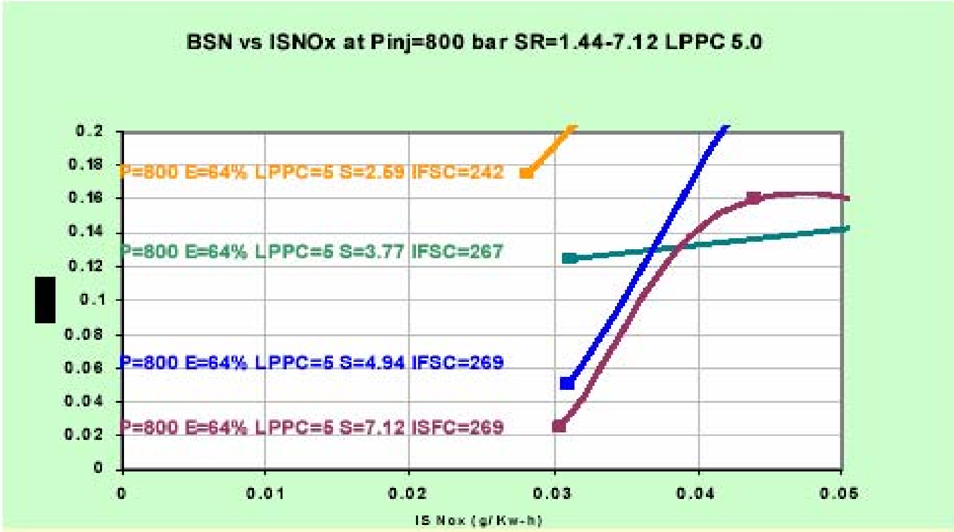


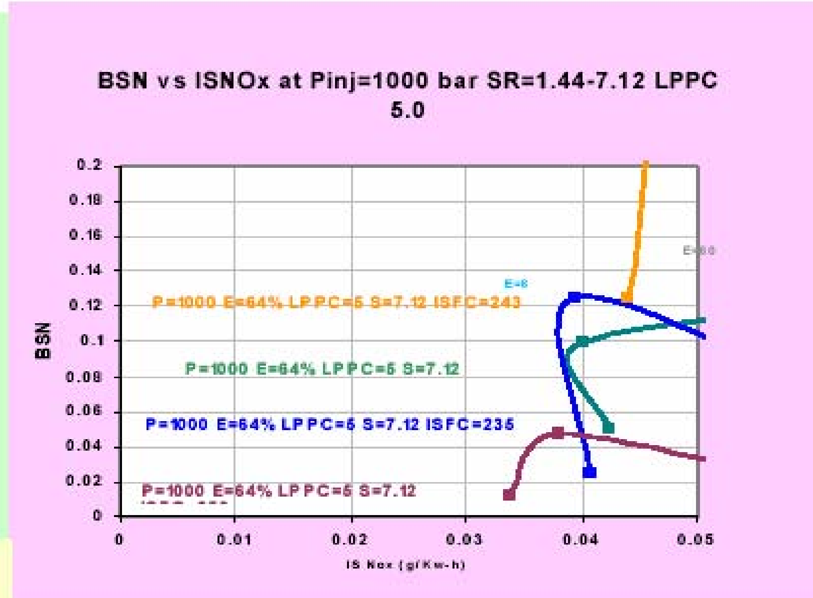
STRATEGIES TO MINIMIZE ENGINE OUT EMISSIONS:

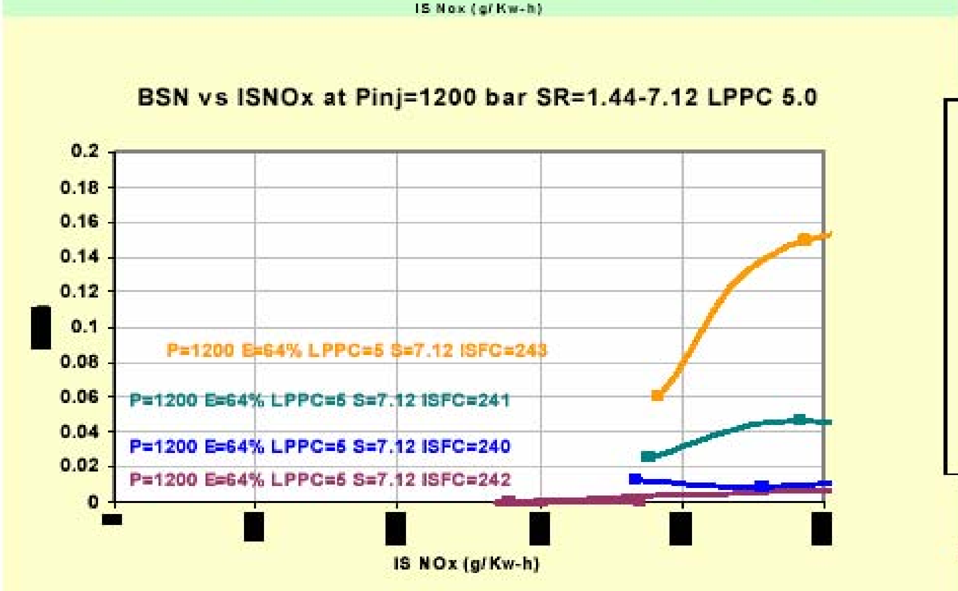
NOx : 0.06 g/l kW.Hr

BSN: 0.2









Strategies to reach the minimum IS NOx and BSU

P=800 ISFC varies from **242 to 267**
P=1000 ISFC varies from **235 to 253**
P=1200 ISFC varies from **240 to 243**

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CONCLUSIONS

Conclusions are based on tests conducted on a single cylinder small bore CIDI diesel engine under steady state conditions in the conventional diesel combustion and LTC Regimes:

1. Operation of the engine in the LTC Regimes has the potential of reducing the demands on the Aftertreatment devices since both NOX are fairly low in addition these regimes are characterized by high HC's and CO thus keeping the catalyst warmed up.

2. 2-D and 3-D Trade Off maps have been developed to show the Trade off between NOx, BSU, HC, CO and T-Exh.

CONCLUSIONS (Continued)

3. The maps can be used to identify the operating zones for the engine parameters to deliver the most suitable composition and Temperature of the feed gas to the Aftertreatment devices (LNT, CRT and CDPF).
4. Some concerns about the operation of the after treatment devices under real life engine transient operating conditions need to be addressed.
5. To meet the emission standards without or with minimum penalty in fuel economy, initial and maintenance cost, the design of the combustion chamber and the control of the injection system and after treatment device need to be integrated.

Thank you for your attention

CONCLUSIONS

1. Combinations of different engine operating parameters obtained from the trade-off maps can deliver the feed gas with the proper composition for LNT, CRT and CDPF.
2. Some concerns about the operation of the after treatment devices under real life engine transient operating conditions need to be addressed.
3. To meet the emission standards without or with minimum penalty in fuel economy, initial and maintenance cost, the design of the combustion chamber and the control of the injection system and after treatment device need to be integrated.

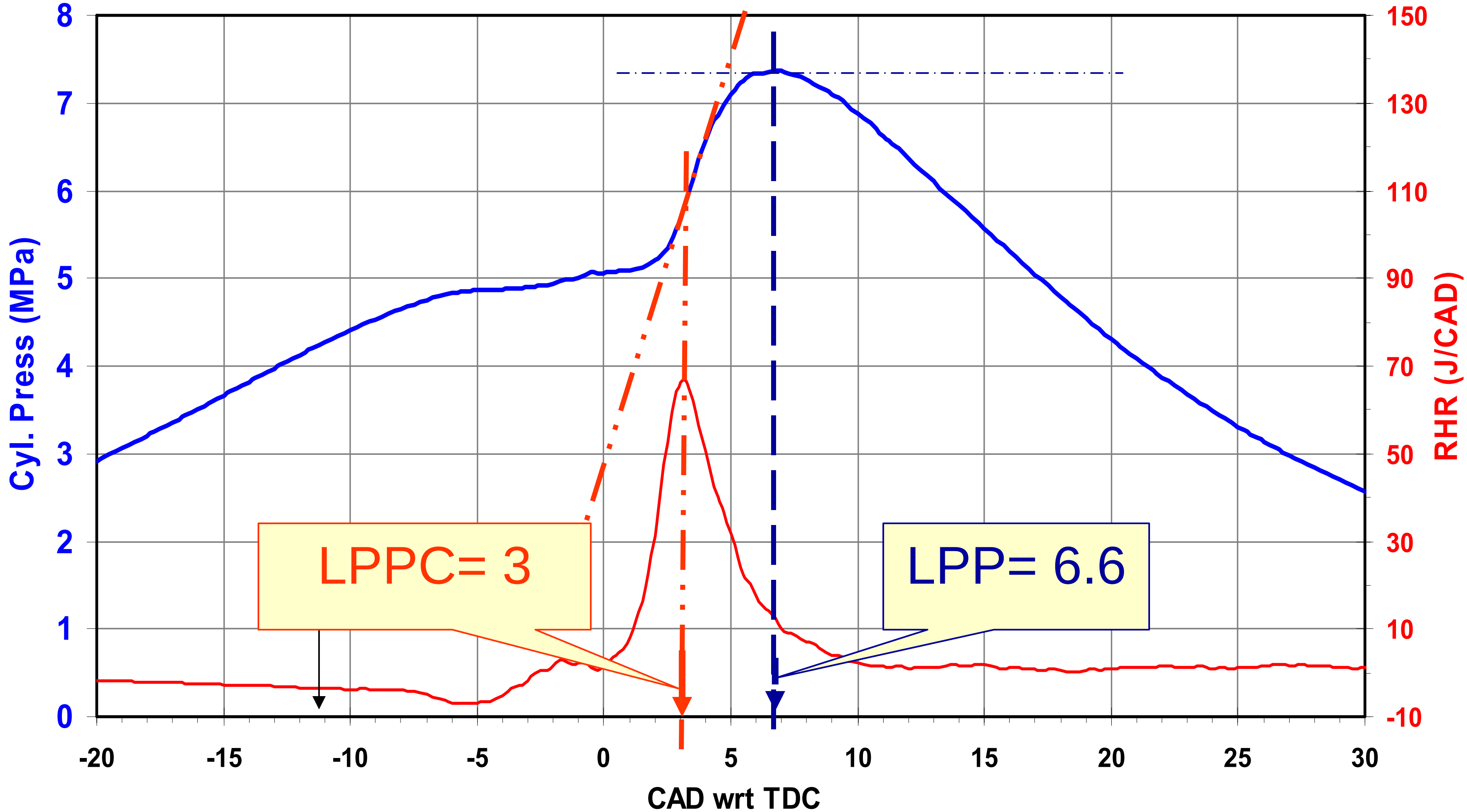
MAJOR CHARACTERISTICS OF THE SMALL BORE CIDI ENGINE:

At LPPC=5°atdc

- High EGR rates reduce NOx, and increase smoke to a point where any further increase in EGR reduces smoke in addition to NOx. This is associated with a noticeable penalty in fuel economy and an increase in HC and CO and ..
- The same phenomena occurred at all the swirl ratios.
- At high EGR rates, the increase in the swirl ratios reduced each of NOx and smoke when they are high.
- The above two effects apply at all the injection pressures tested so far.

OPERAS on the road to the in the smokeless Noxless regime showed the following: !. Better trade-off than the MK system, better ISFC and more stable engine operation at IMEP=3 bar and 1500 rpm. To achieve the same results at IMEP=6bar and 2000 rpm, the fuel injection system needs to be upgraded. Currently another startegy is under investigation with the goal of improving fuel economy and integrating the engine with the aftertreatment controls.The results achieved so far have been limited with the capabilities of the hard ware. Better results are expected if the ihardware, and in particular the injection system is improved..

Sample cylinder pressure & RHR traces Reference Timing Points



BACKGROUND

- Diesel combustion and engine-out gas composition in small bore diesel engines depends on several design and operating parameters that have a great impact on spray atomization, evaporation, mixing, wall impingement, ignition delay, premixed combustion fraction, injection in a well established flame, mixing controlled and diffusion controlled combustion fractions.
- The proper gas composition for the after treatment devices can be obtained by **O**ptimizing the main following players Injection **P**ressure, **E**GR, Injection timing **R**etard or **A**dvance and **S**wirl Ratio. **"OPERAS"**

BACKGROUND

- The presentation today is based on data obtained in a program entitled "Characterization of Single-Cylinder Small-Bore, 4-Stroke CIDI Engine Combustion".
- This program is sponsored by DOE Office of FreedomCar and Vehicle Technologies under the leadership of Gurpreet Singh, and the technical direction of Dennis Siebers, Manager Engine Combustion, Sandia National Lab.
- Other support comes from U.S. Army TARDEC, NAC and ARC.
- In this presentation we will look at the engine as a part of a system composed of the engine and the after treatment devices.
- Different types of after treatment devices might be needed for the diesel engine to meet the strict future emission standards, particularly for NOx and PM.
- The efficiency of any after-treatment device depends on the properties of the feed gas, mainly its composition, temperature, …
- The properties of the feed gas are the result of the in-cylinder combustion process
- New diesel combustion regimes have been developed during the last five years.

TESTS MATRIX

Nozzles : 430 VCO, 390 Mini-Sac, 320 Mini-Sac

Test Points:

	RPM	IMEP(Bar)	MAP(Bar)
KP1	900	1.2	1.0
KP2	1500	3.0	1.2
KP3	2000	5.0	1.4
KP MK1	2000	7.0	1.4
KP MK2	1500	3.0	1.1

Injection Pressures: 400, 600, 800, 1000, 1200 Bar

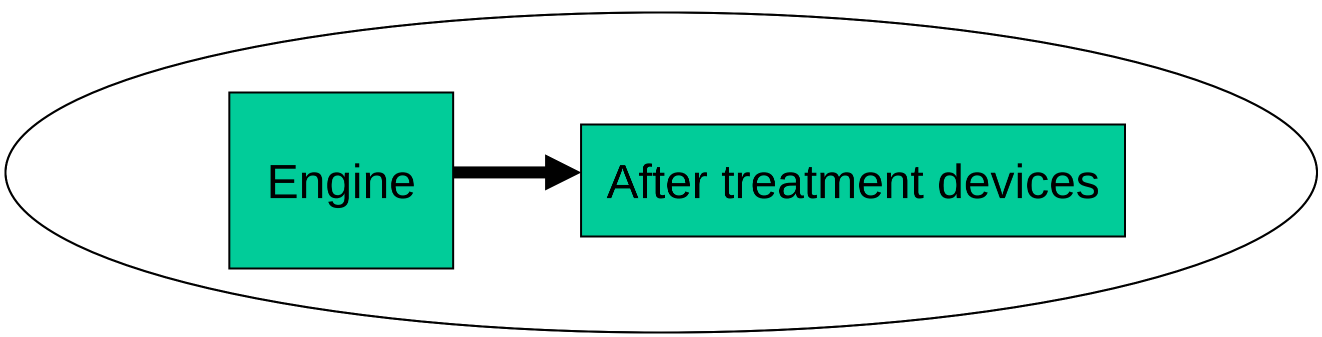
Injection Modes: Main, Pilot-Main, Main-Post

EGR ratios: 0%, 25%, 35%, 40%, 45%, 50%, 55%

Swirl Ratios: 1.5 – 3.00

Injection timing: LPP = 6 –7°aTDC to misfiring line

ENGINE ROAD MAP TO PRODUCE THE PROPER FEED GAS TO THE AFTER-TREATMENT DEVICES.

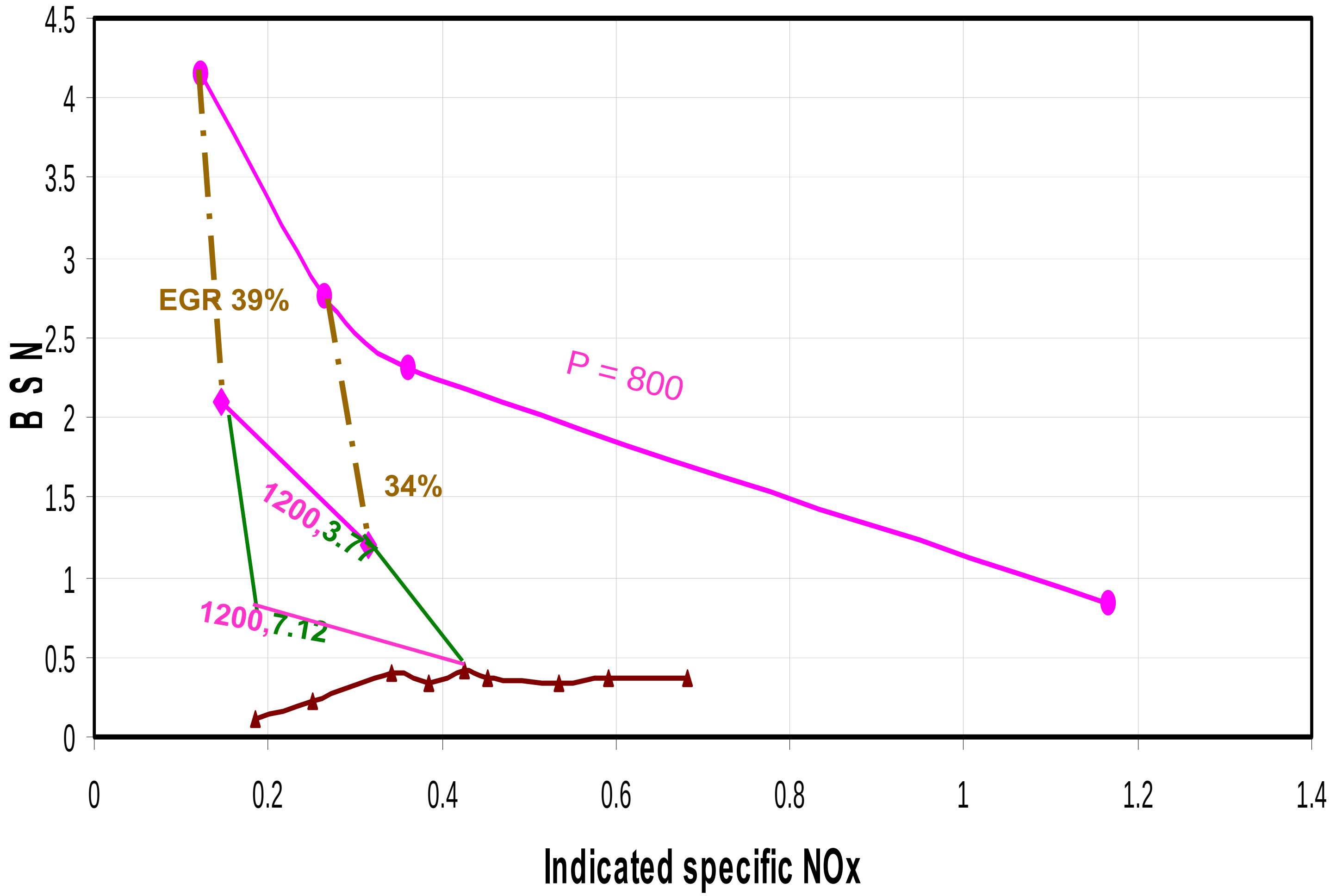


ROAD MAP TO THE MINIMUM NOx AND BSU IN LTC REGIME AT IMEP = 6 bar & 1500 RPM

EFFECT OF INJECTION TIMING

Effect of Injection Timing

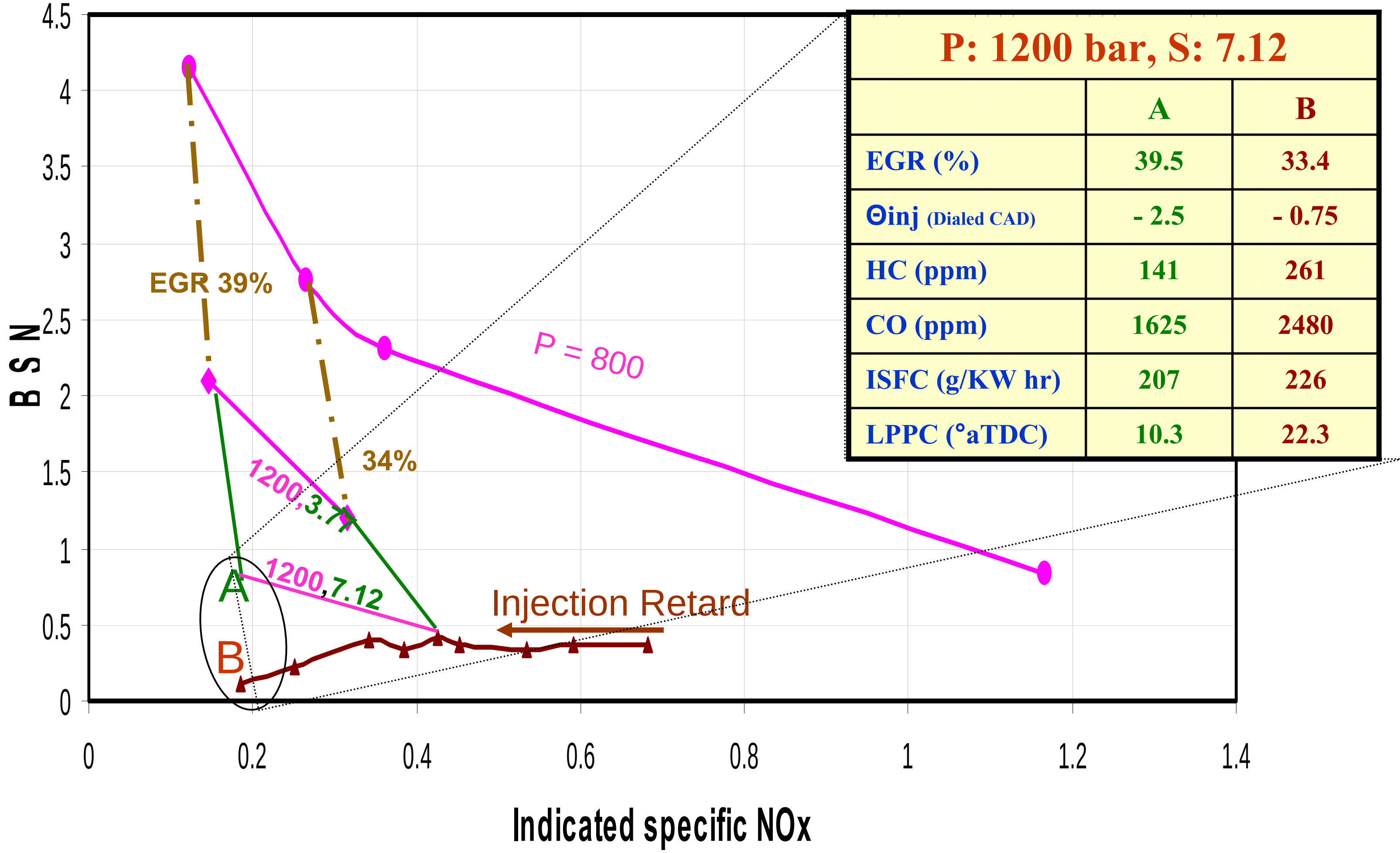
•IMEP = 6 bar	Θinj (Dialed CAD)= -6 to -0.75	
•1500 RPM	Variable EGR = 34%	SR= 7.12



Comparison between the optimum trade-off points for two injection strategies

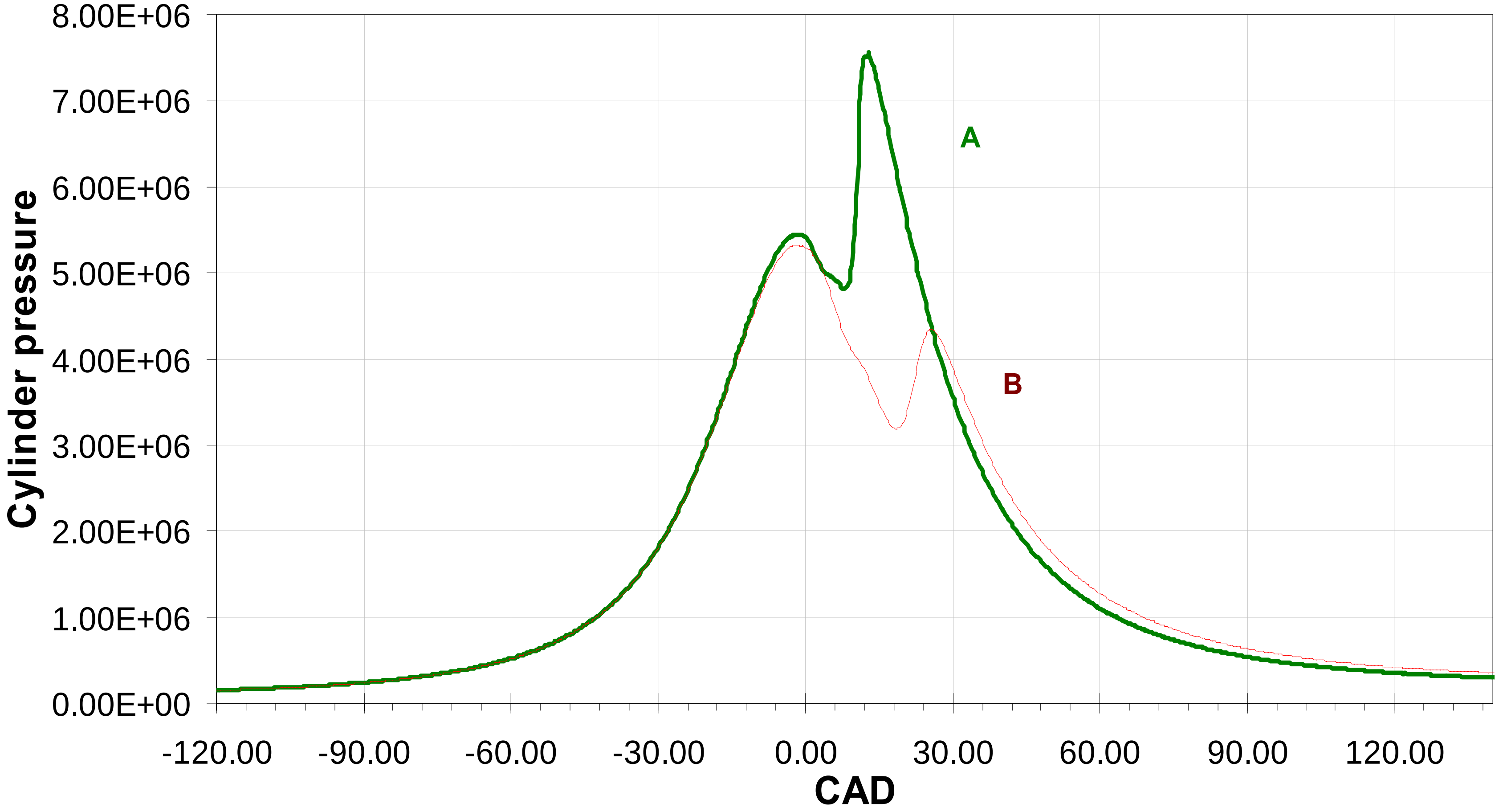
- IMEP = 6 bar
- 1500 RPM

Θinj (Dialed CAD)= Variable
Variable EGR = 34 to 39%%



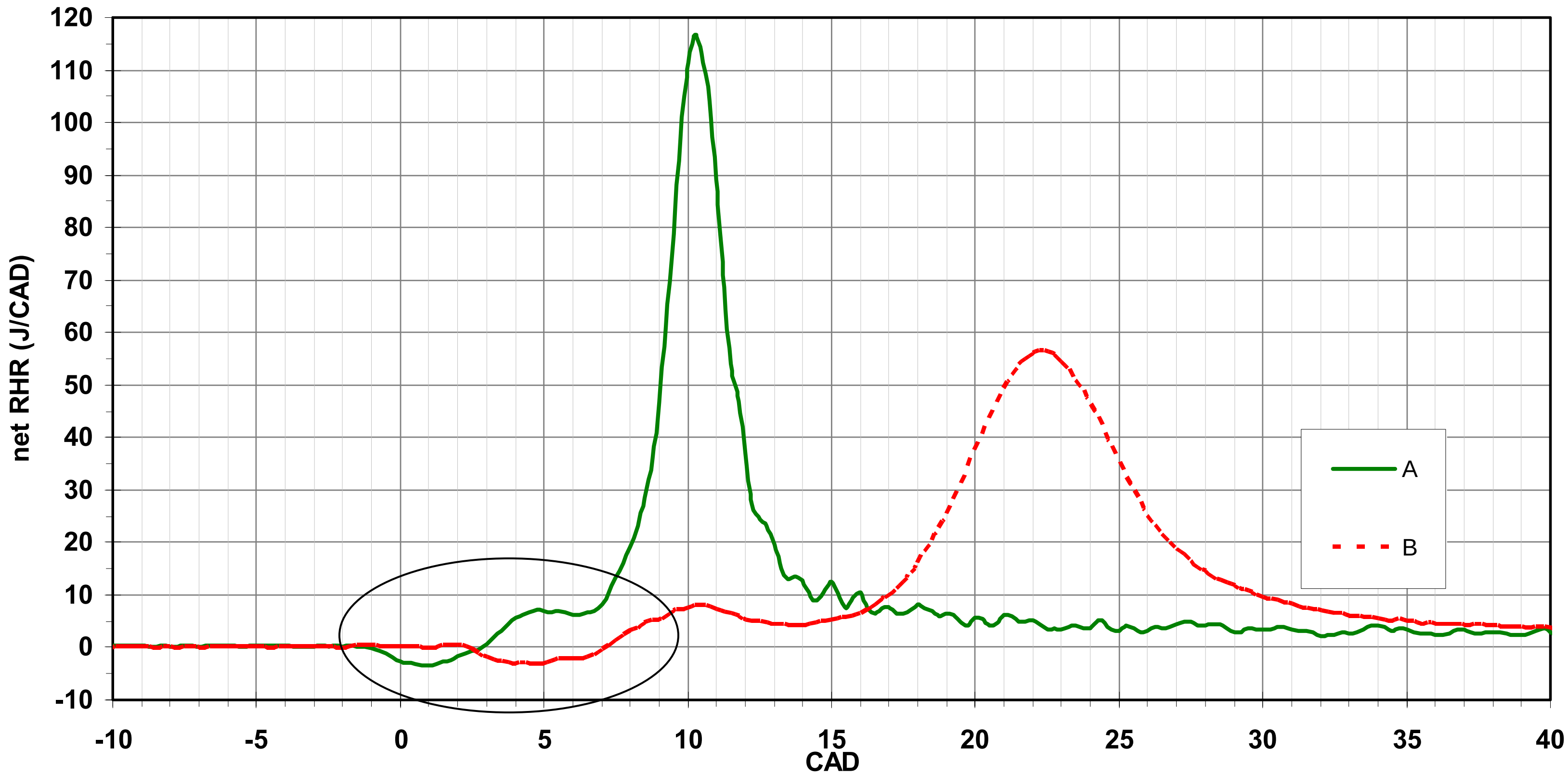
P: 1200 bar, S: 7.12		
	A	B
EGR (%)	39.5	33.4
Θinj (Dialed CAD)	- 2.5	- 0.75
HC (ppm)	141	261
CO (ppm)	1625	2480
ISFC (g/KW hr)	207	226
LPPC (°aTDC)	10.3	22.3

Comparison Between POINTS A&B (P-θ)



Comparison Between POINTS A&B (RHR)

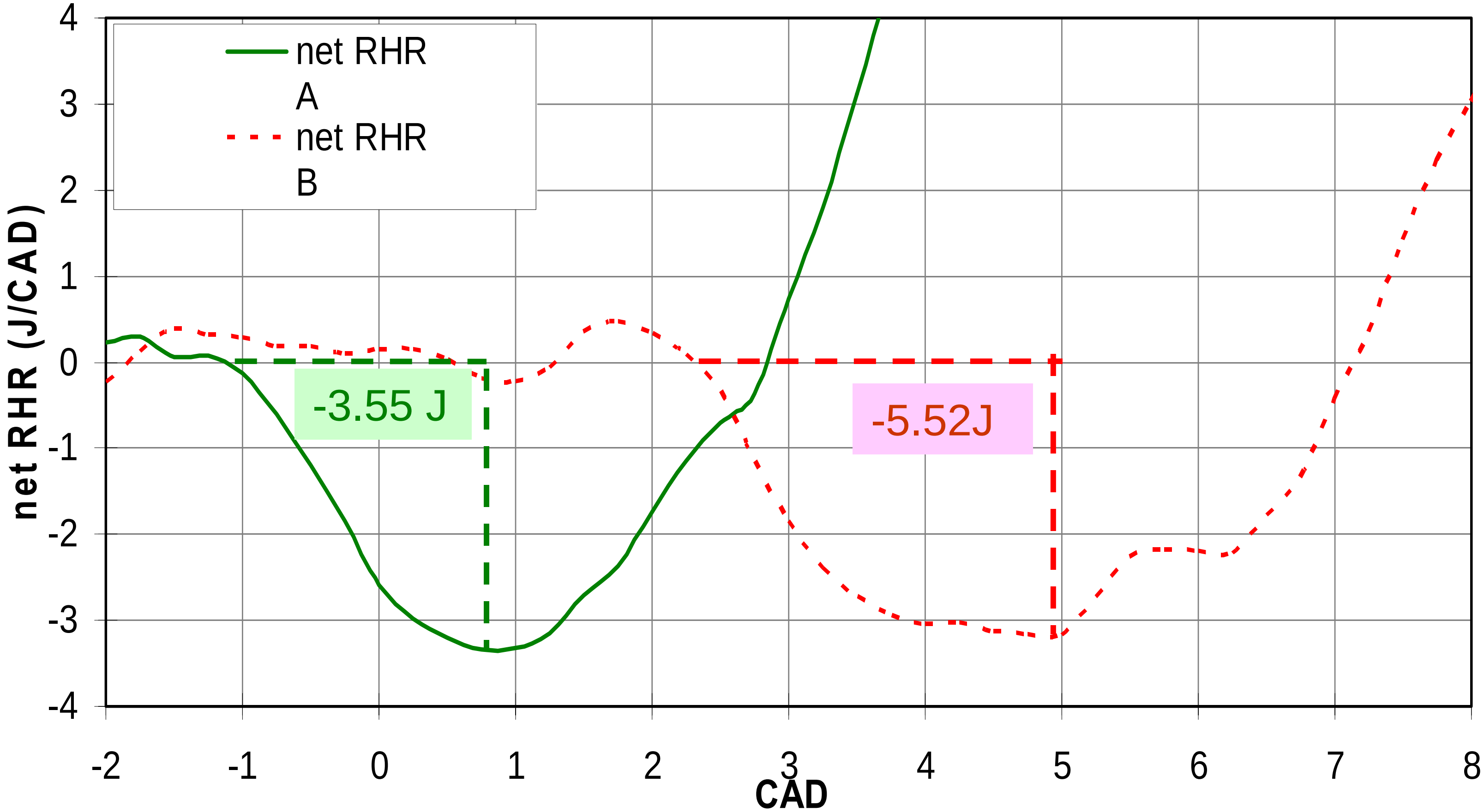
- •IMEP = 6 bar — Θinj (Dialed CAD)= -2.5(A), -0.75(B)
- •1500 RPM, — Pinj=1200 bar — EGR = 34%(A) ,39%(B)



Comparison Between POINTS A&B

(Energy in fuel evaporation & Endothermic reactions)

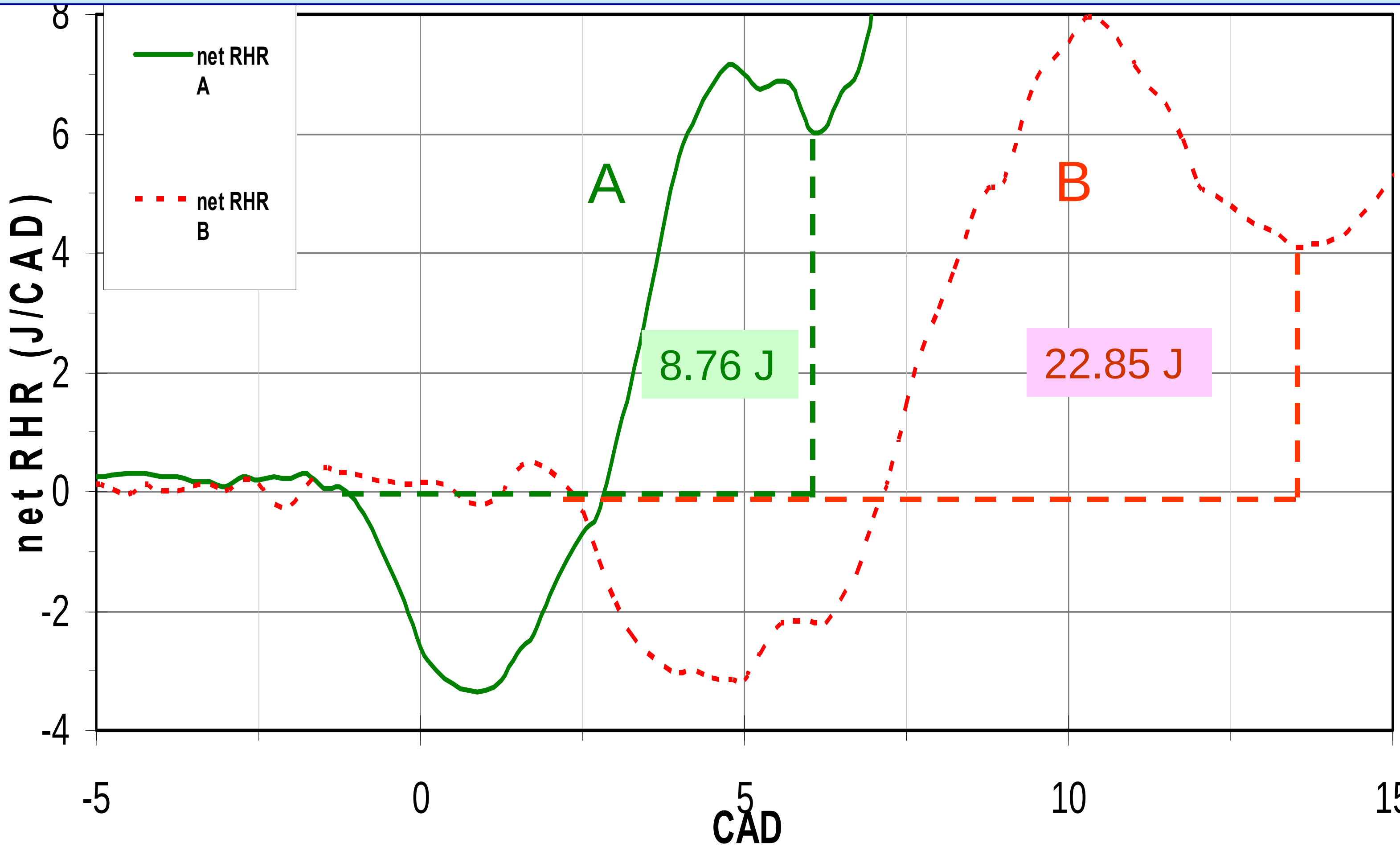
- IMEP = 6 bar   Θinj (Dialed CAD)= -2.5(A), -0.75(B)
- 1500 RPM,   Pinj=1200 bar   EGR = 34%(A) ,39%(B)



Comparison Between POINTS A&B

(Energy in fuel evaporation, Endothermic reactions & Cool flame)

- IMEP = 6 bar — Θinj (Dialed CAD)= -2.5(A), -0.75(B)
- 1500 RPM, — Pinj=1200 bar — EGR = 34%(A) ,39%(B)



The main barrier for A into LTC regime at IMEP = 6 bar & 1500 RPM

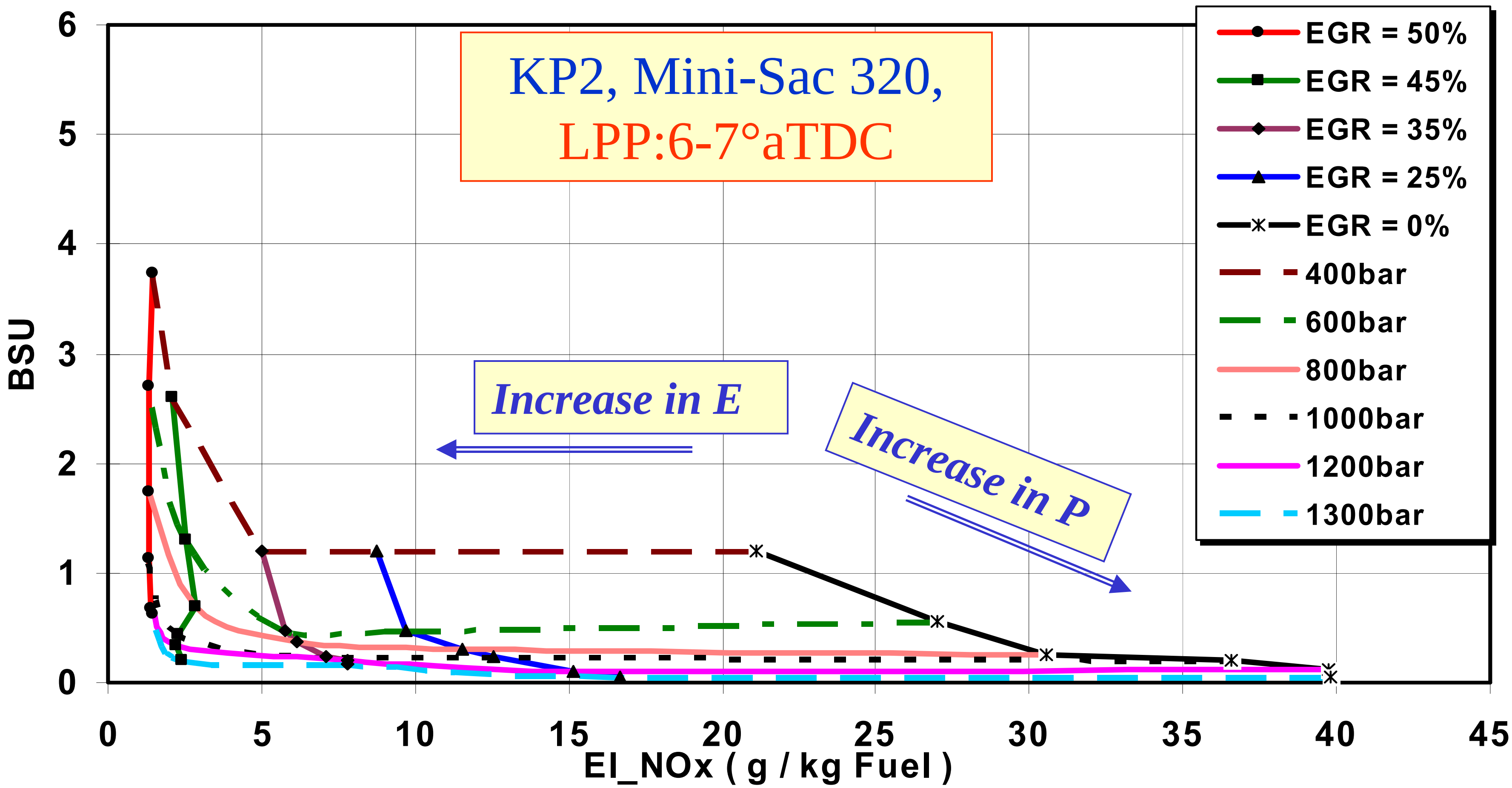
Concept: The main barrier for point A to move closer to Zero is the lack of proper mixing of the fuel vapor and the fresh charge that has lower oxygen content.

Proposed strategy to remove the barrier with the current limitations of the CIDI engine hardware

1. Advance injection timing, have LPPC at 5°aTDC to stabilize combustion at higher EGR rates
2. Apply injection pressures higher than 1200 bar to improve premixing.
3. Increase EGR to reduce O_2 concentration and increase ID to allow more time for mixing

More advanced injection systems can apply **different** and more effective **strategies**

EFFECT OF Pinj and EGR on the TRADE-OFF between BSU and NOx



LEAN NOx CATALYST
OPERAS

- The best HC/NO ratio depends on the type of catalyst formulation, precious metal loading, hydrocarbon speciation, species used for the reaction, the temperature, exhaust oxygen content, space velocity, speed and load on the engine.

- HC/NO ratio of 3.88* was found to be the optimum ratio for a LNC, at a loading condition close to that used in this investigation.

  ****“Research Approach for Aging and Evaluating Diesel Lean-NOx Catalysts,” Wayne, W.S. et al, SAE 2001-01-3620***

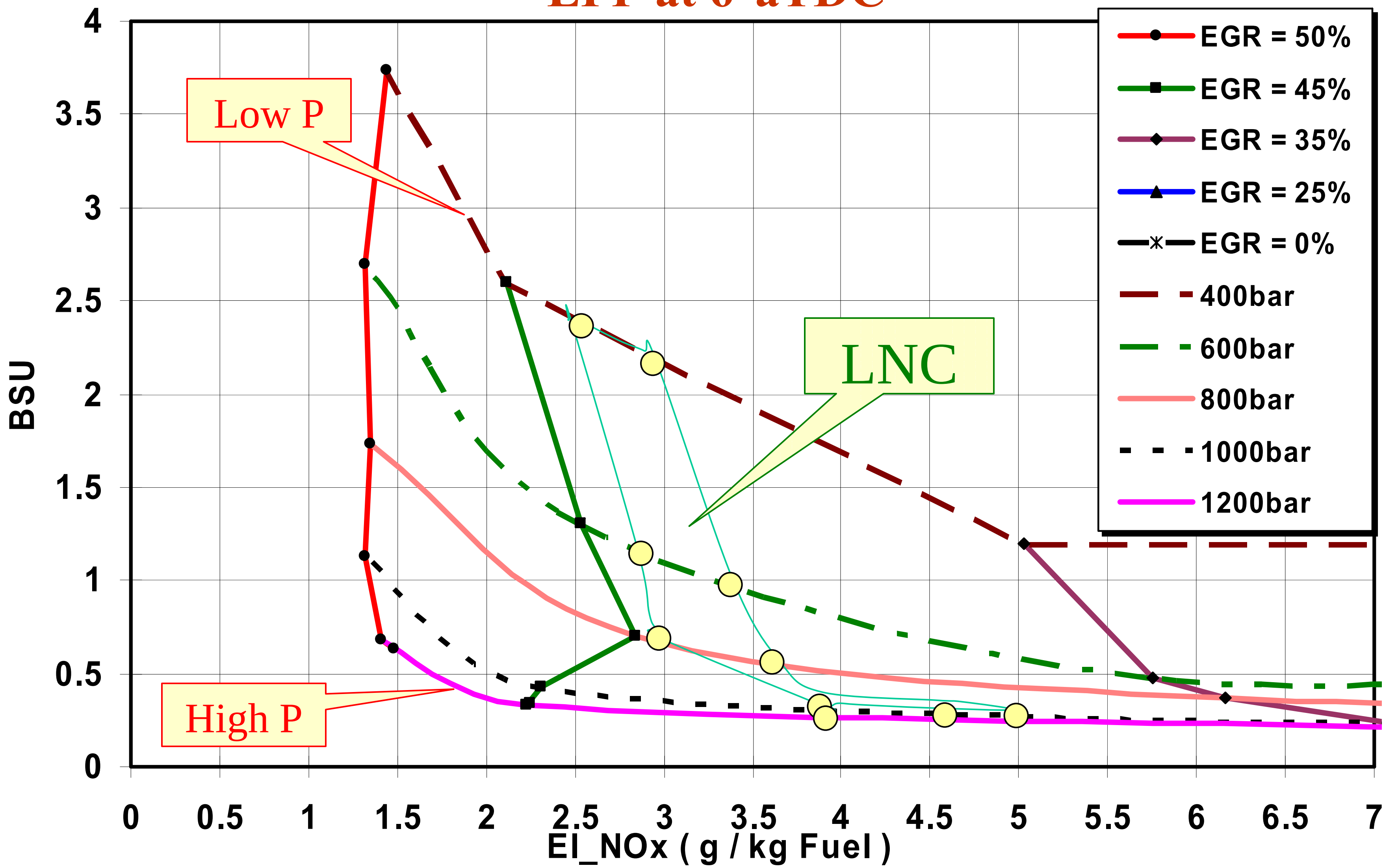
- ***As*** a demonstration in this investigations , we chose HC/NO ratios between 3.5 and 4.0

CHOICE BETWEEN OPERAS

LPP at 6°aTDC

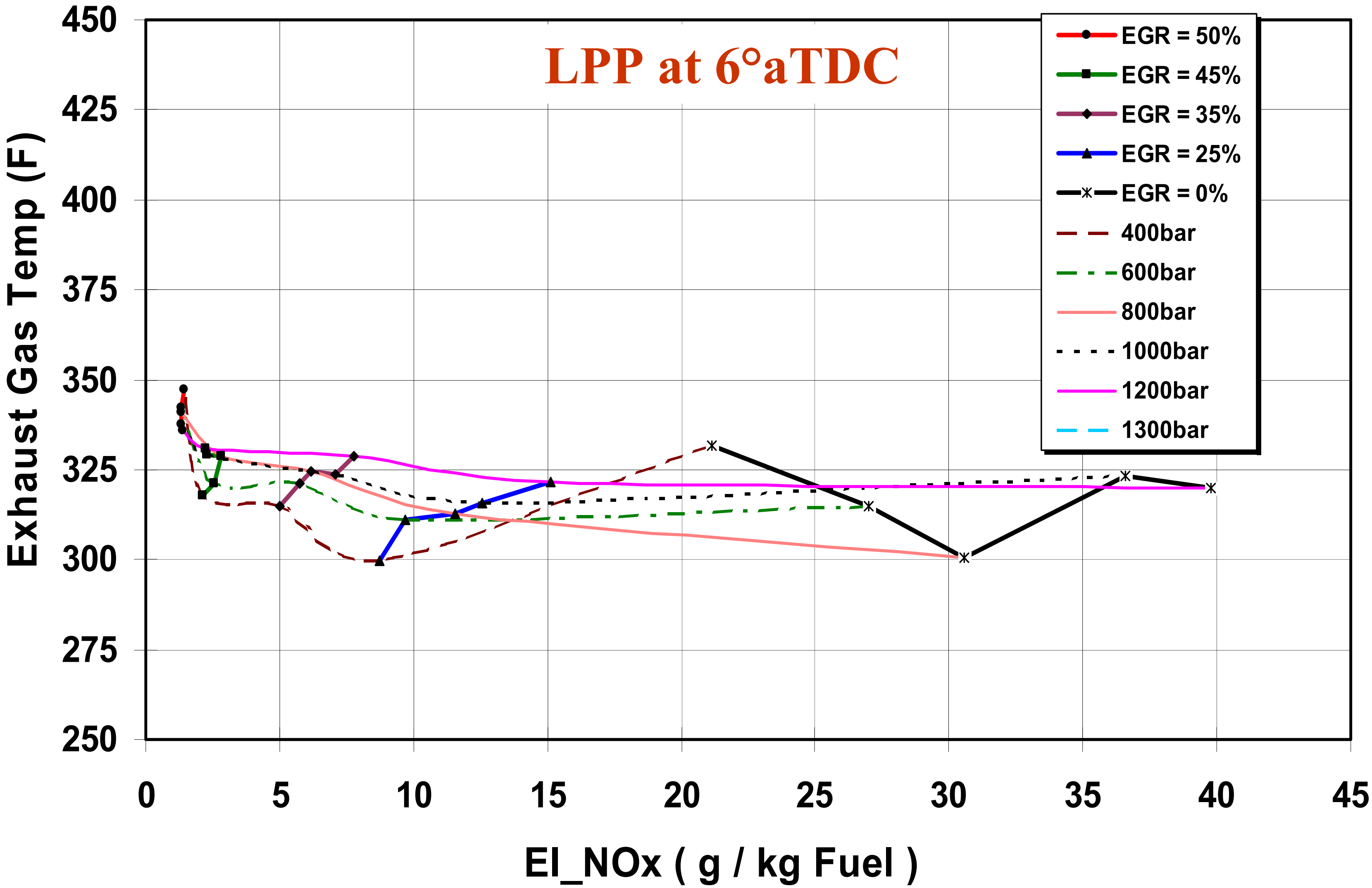
	HIGH P	LOW P	
Initial and maintenance costs		Better	
Engine-out NOx	Better		
PM Mass	Better		
Associated E	Better		
Ultra fine particles		Better	

TRADE-OFF Between NOx and BSU, (KP2 , 320 MINISAC)
LPP at 6°aTDC

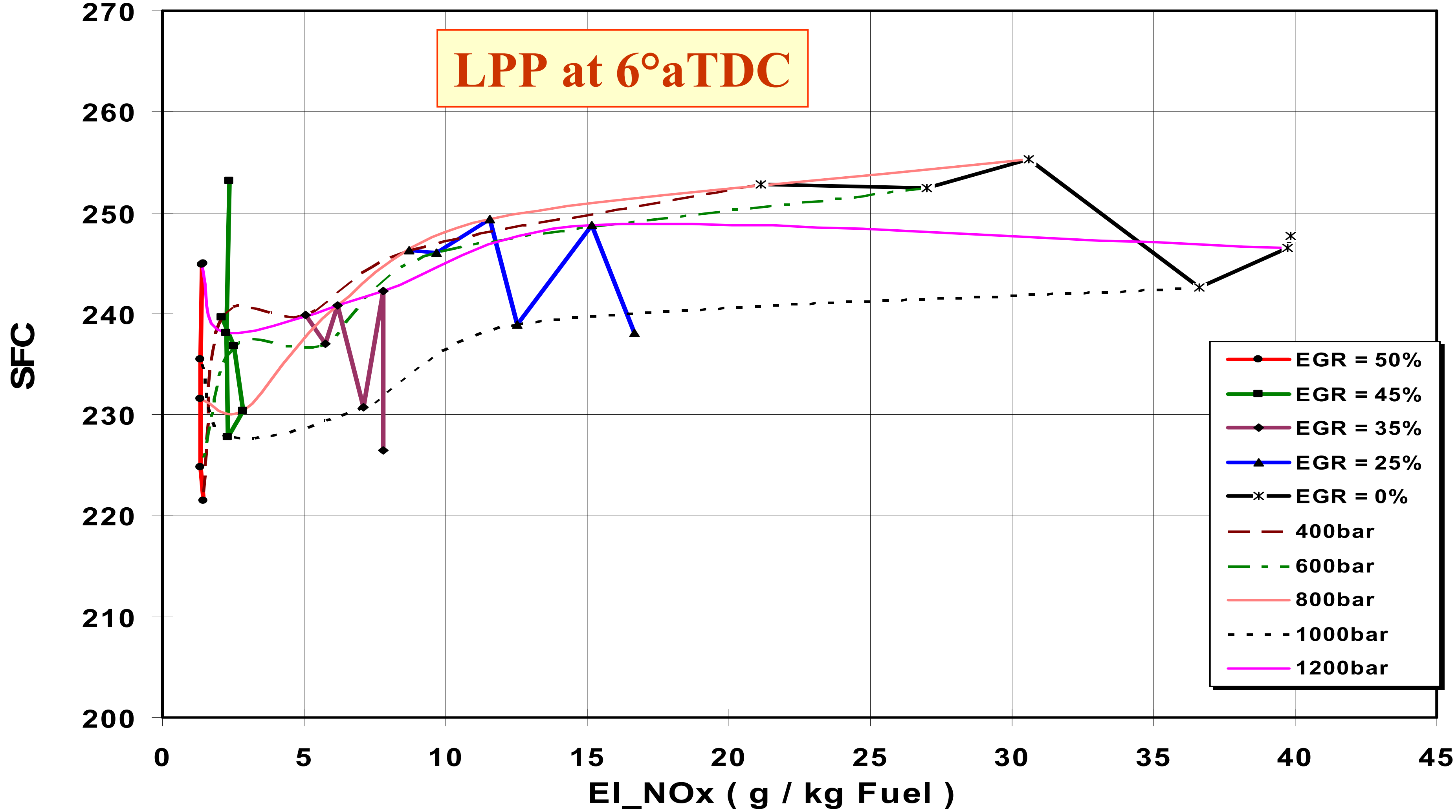


TRADE-OFF Between NOx and Texh (F),

(KP2 , 320 MINISAC)



TRADE-OFF Between SFC and Texh (F), (KP2 , 320 MINISAC)



CONTINUOUSLY-REGENERATING TRAP (CRT) **OPERAS**

NOx / C ratio required is

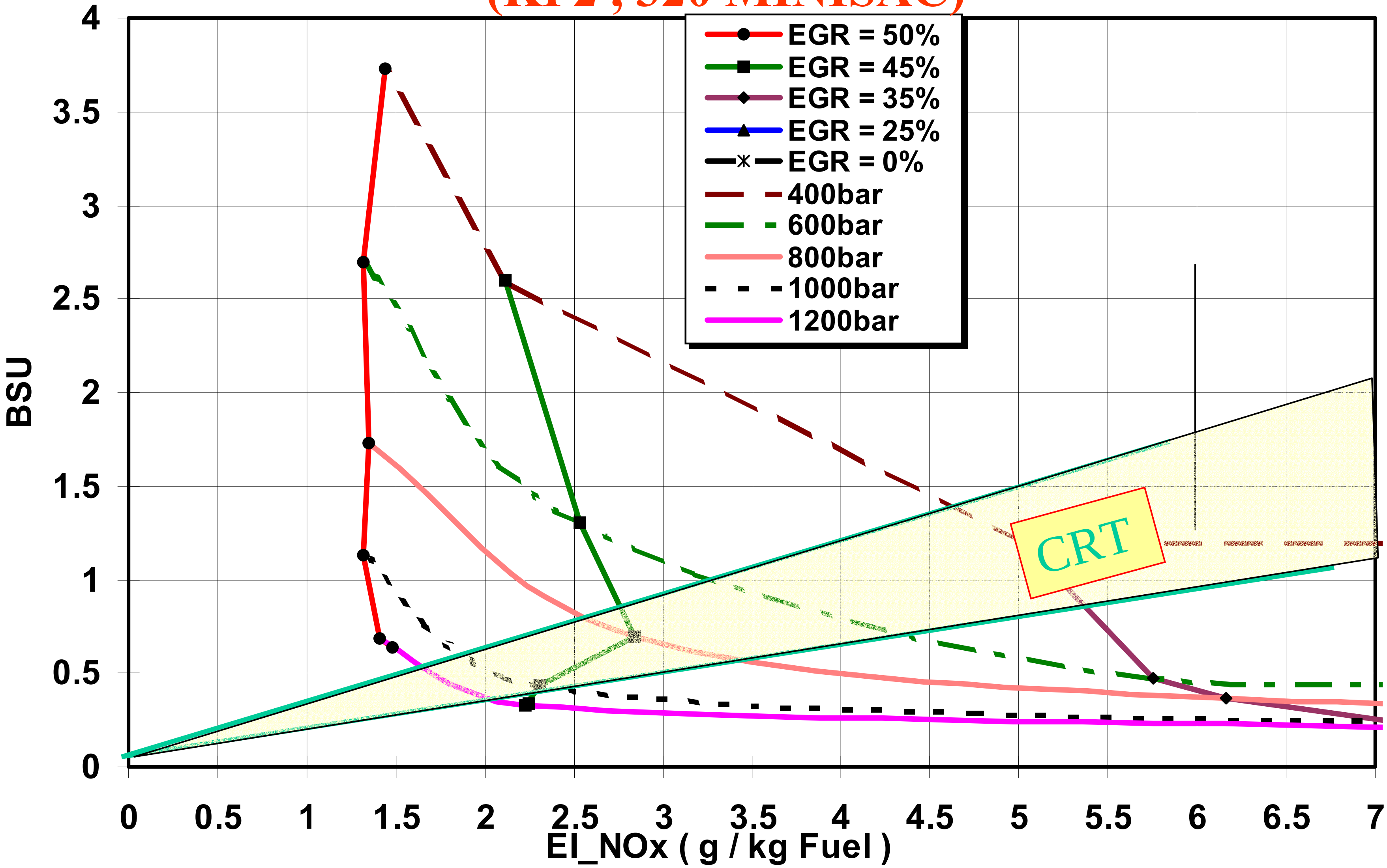
(a) at least 8 *(SAE 2001-01-1947)*

(b) between 16 – 24 in HD engines*(SAE 2003-01-0770)*

•***As*** a demonstration in this investigations , we chose NOx / C ratios between 8 and 16.

TRADE-OFF Between NOx and BSU,

(KP2 , 320 MINISAC)



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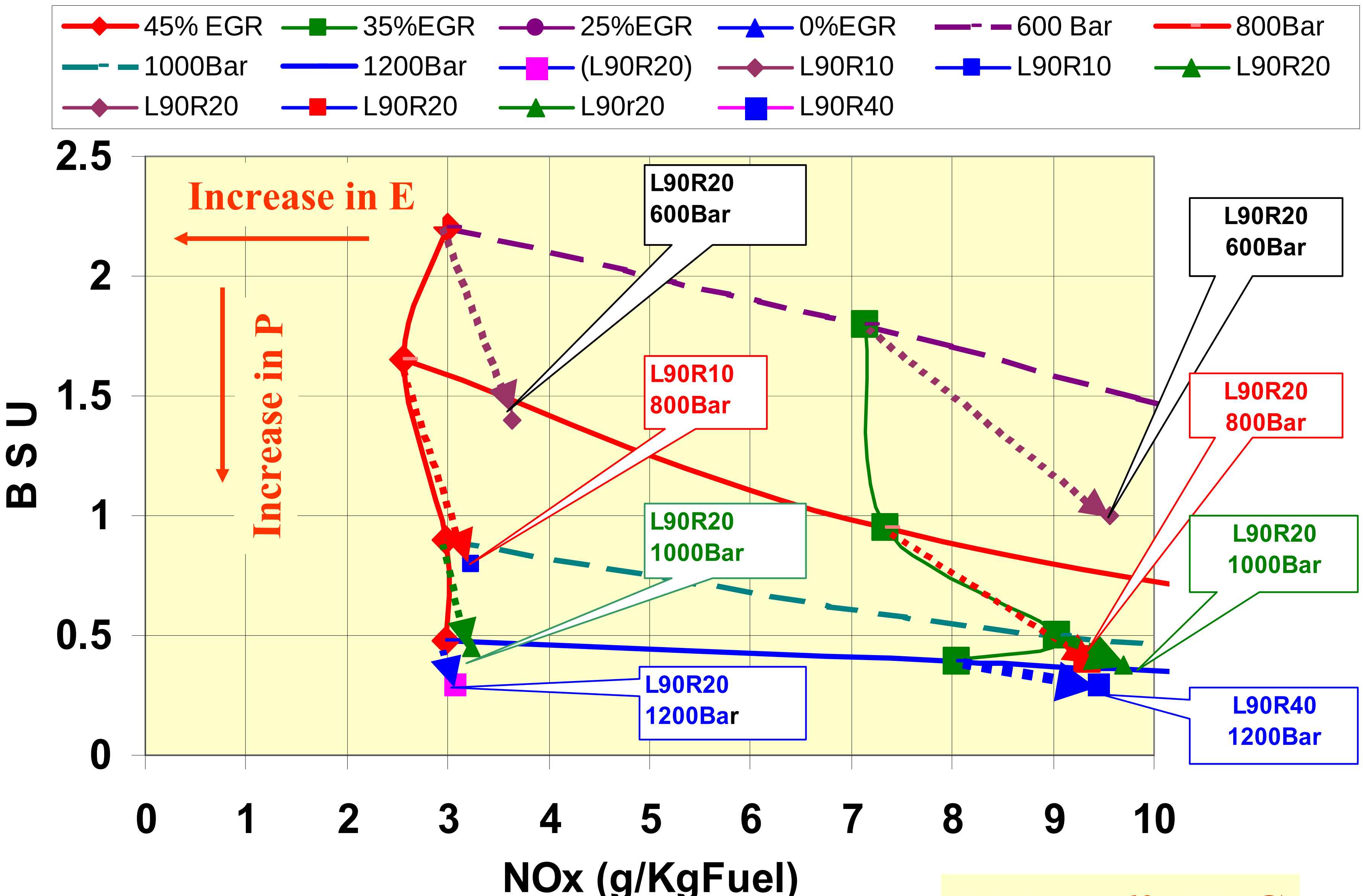
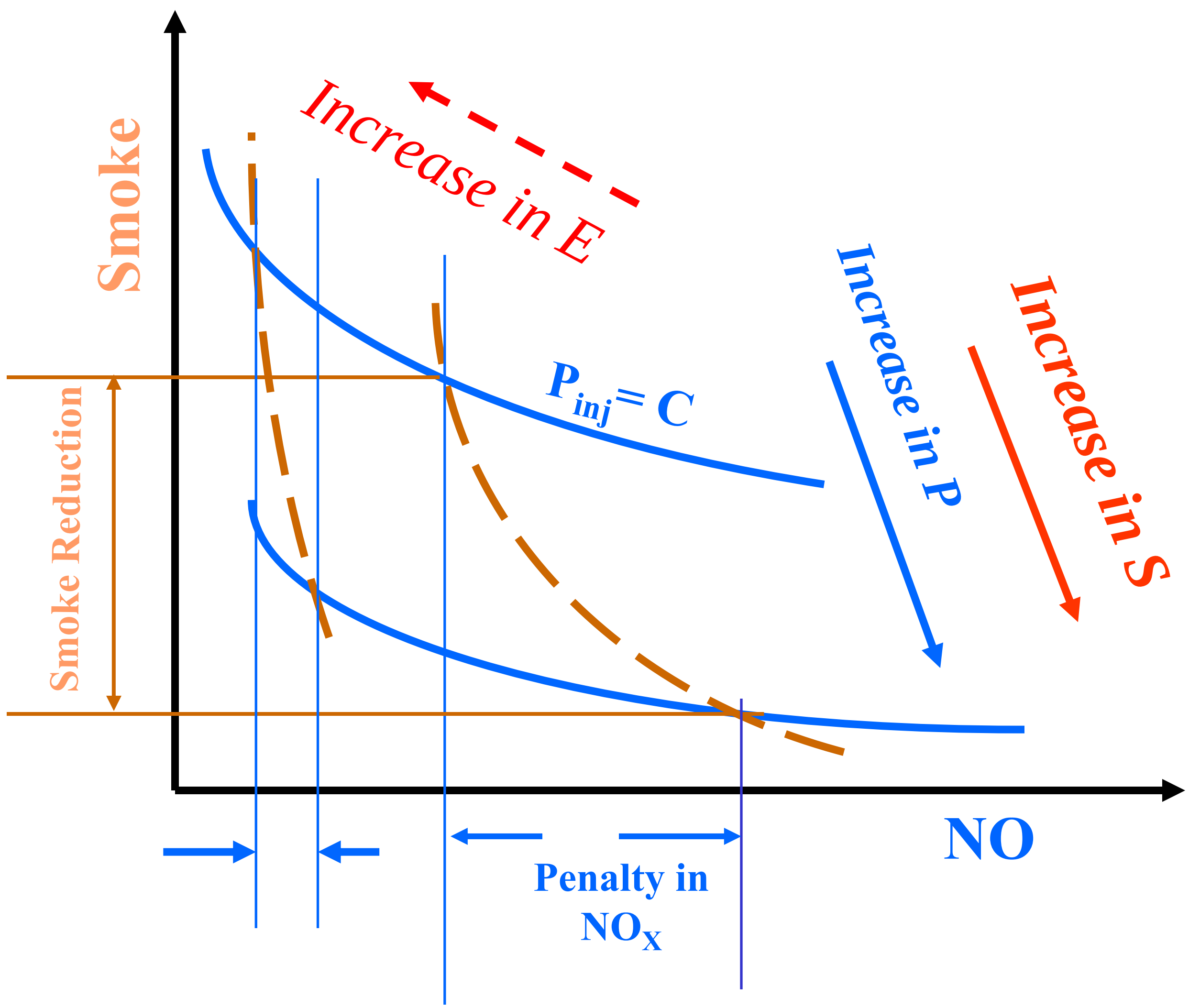
Trade-off Between NOx and BSU at KP3, Minisac-320



RPM=2000,IMEP=500KPa, Tin=170F,Pin=1.40Bar,Pex=1.80Bar,

LPP at 6°aTDC

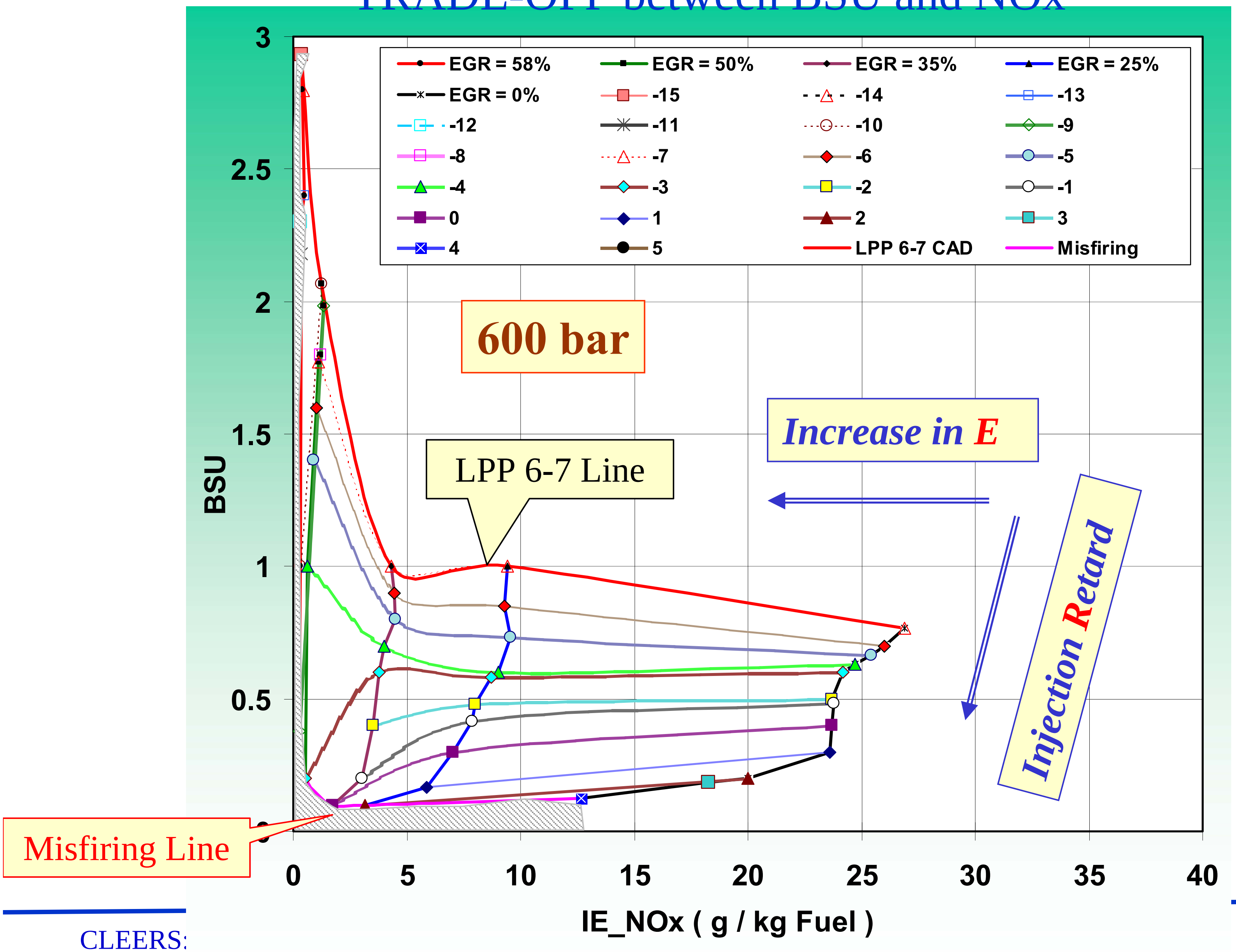
ISO-PLOTS for the TRADE OFF BETWEEN NOx &BSU



600 bar, LTC

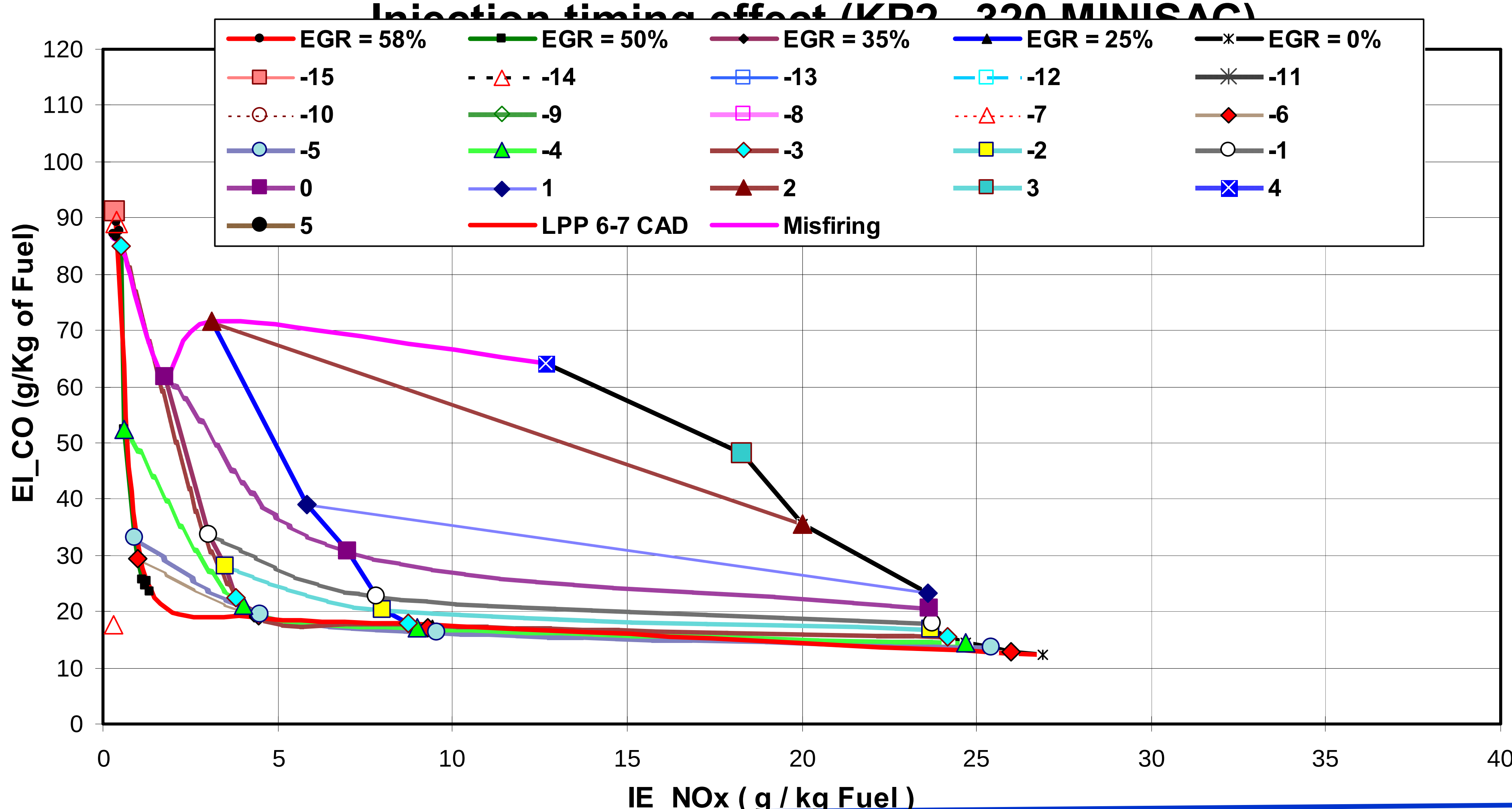
- Characterized by long delay after end of injection
  - Injection retard
  - High EGR

EFFECT OF INJECTION TIMING R &A on the TRADE-OFF between BSU and NOx

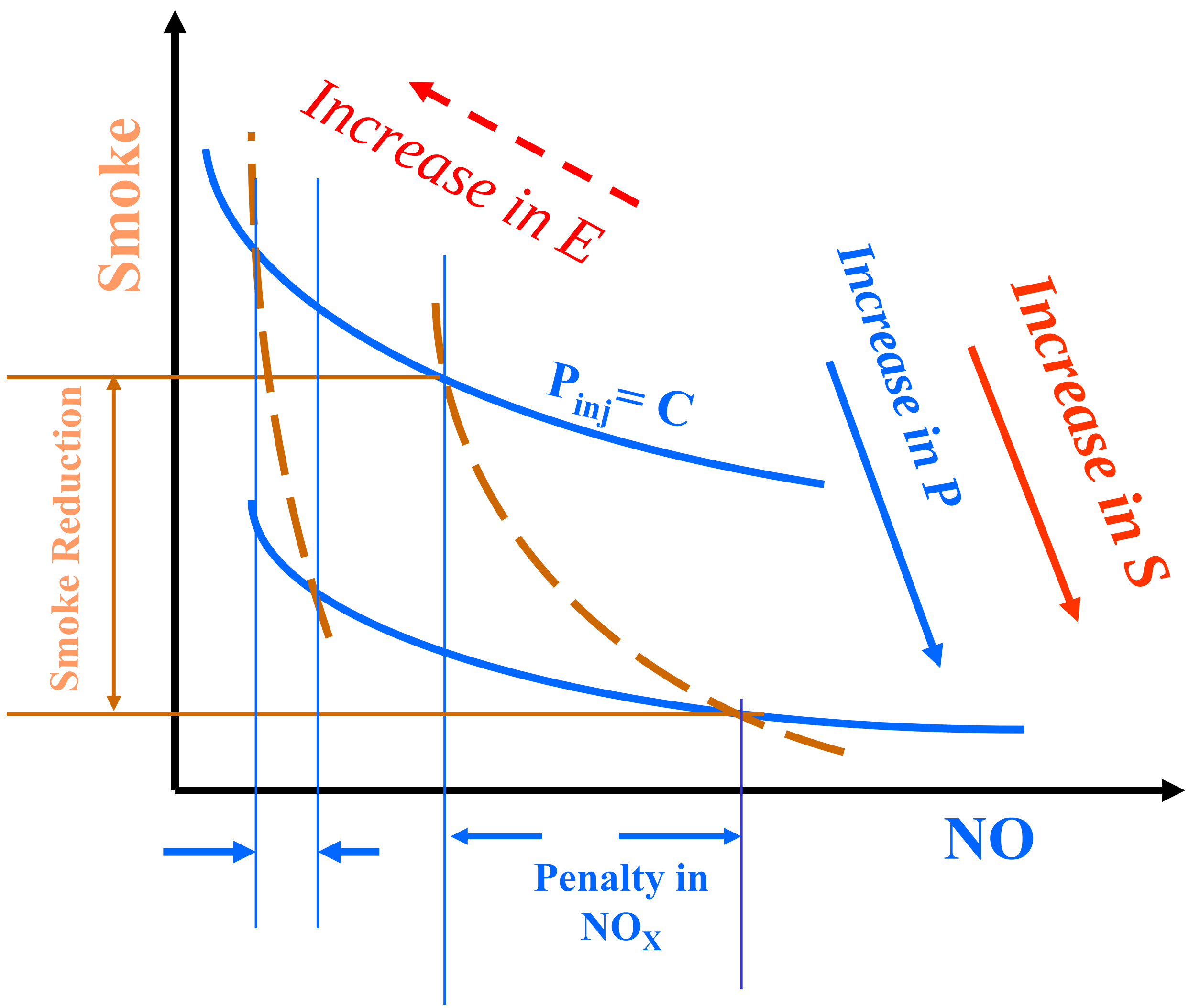


TRADE-OFF Between NOx and CO, 600 bar

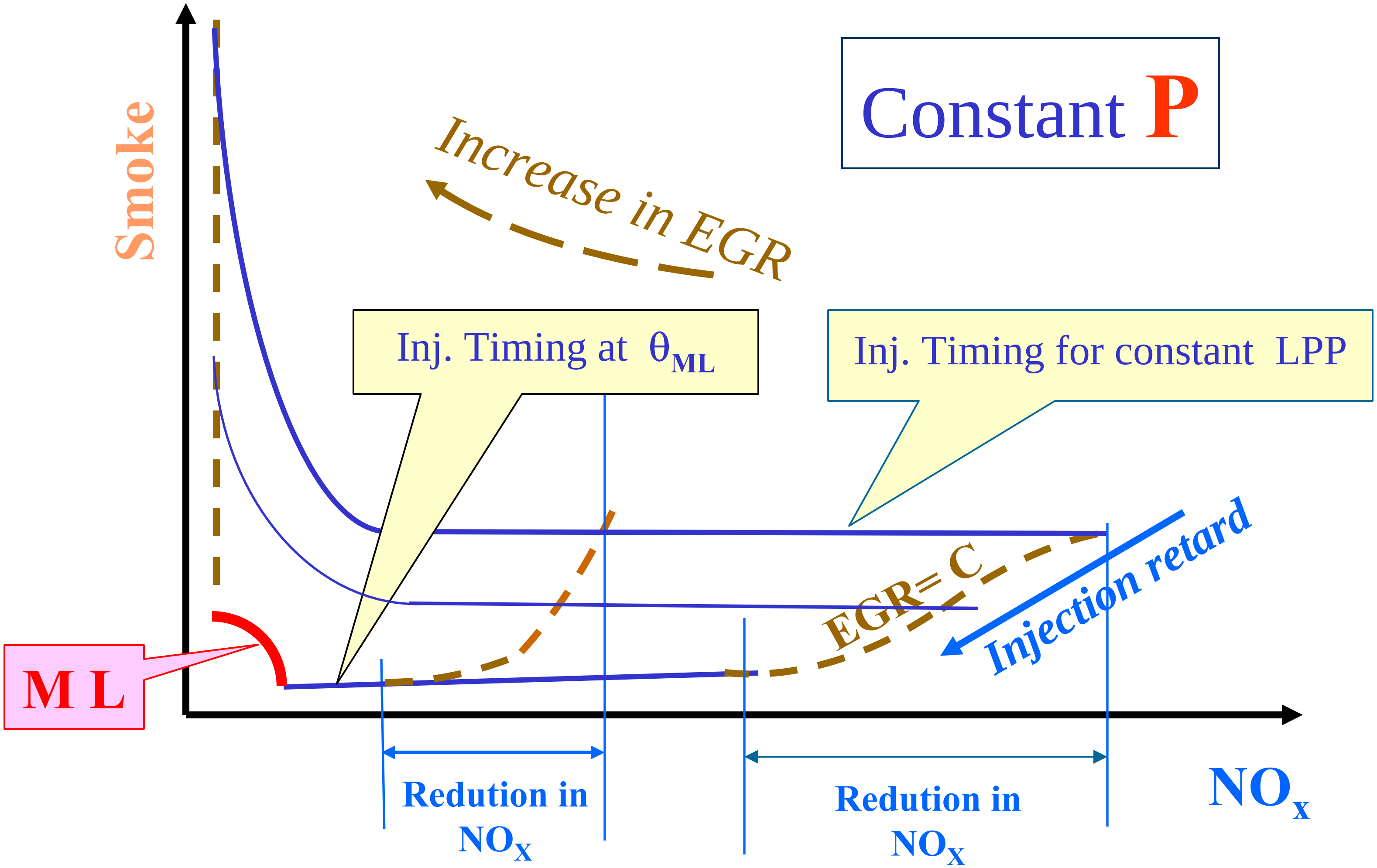
Injection timing effect (KR2 - 320 MINISAC)



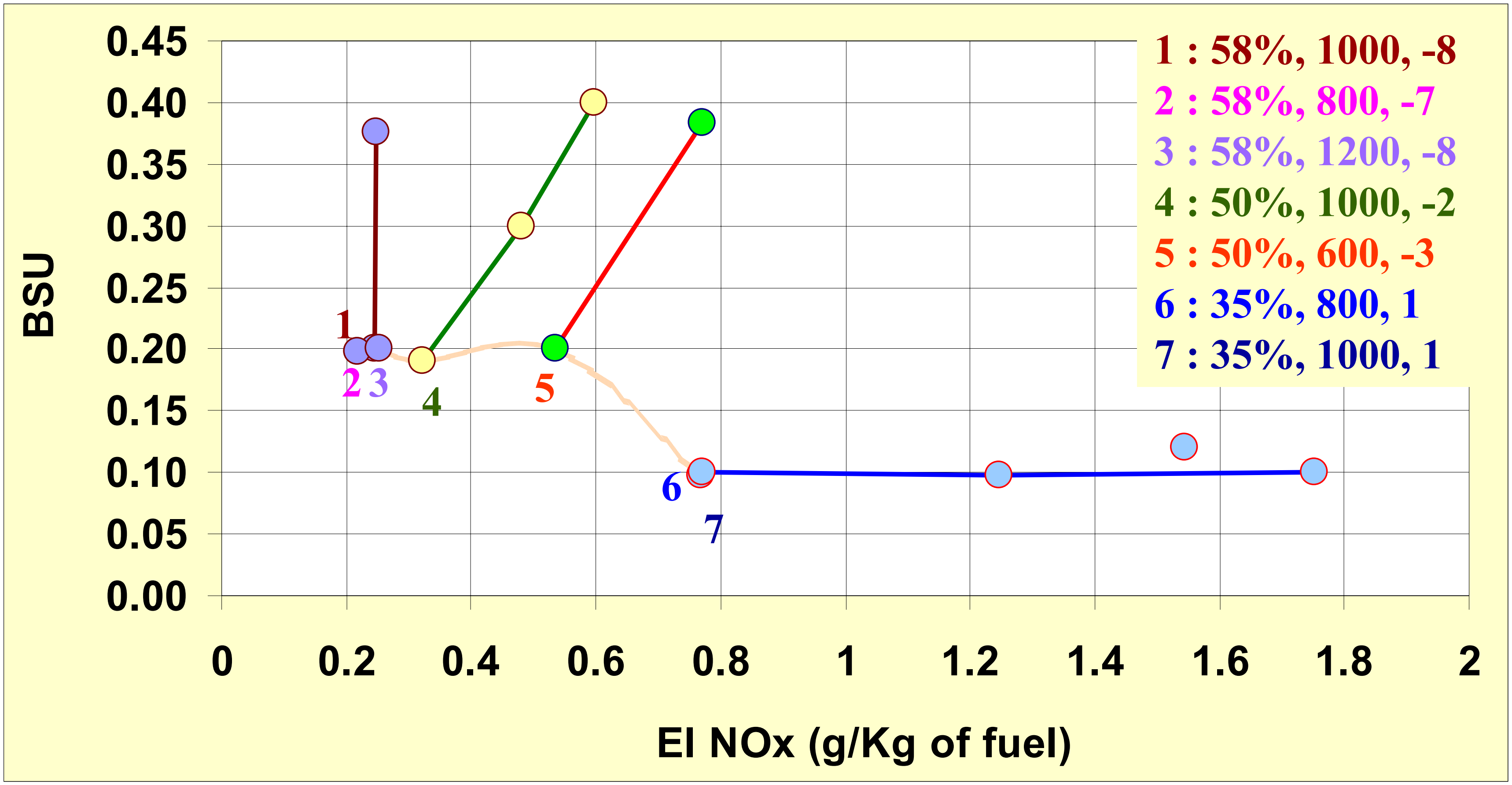
ISO-PLOTS for the TRADE OFF BETWEEN NOx &BSU



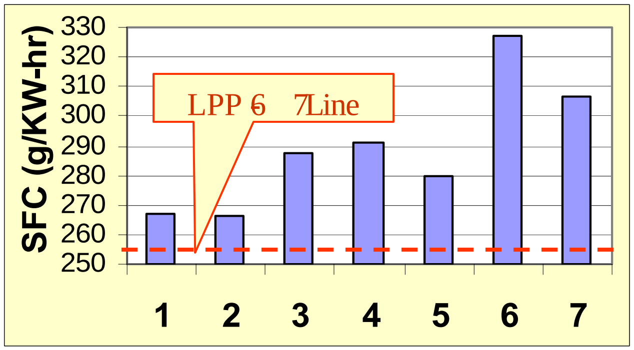
ISO-PLOTS for the TRADE-OFF BETWEEN NOx &BSU

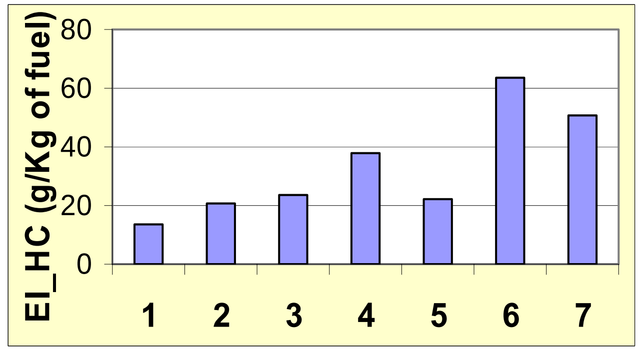


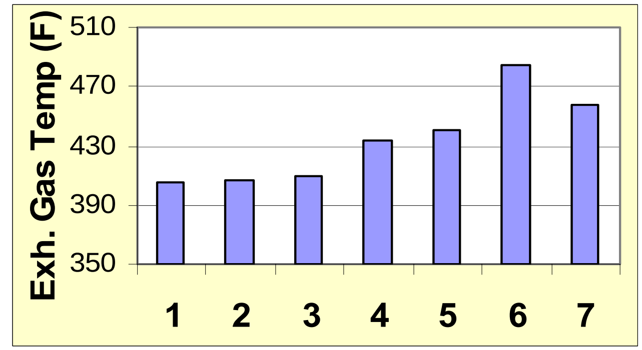
M-L (MISFIRING LINE) POINTS

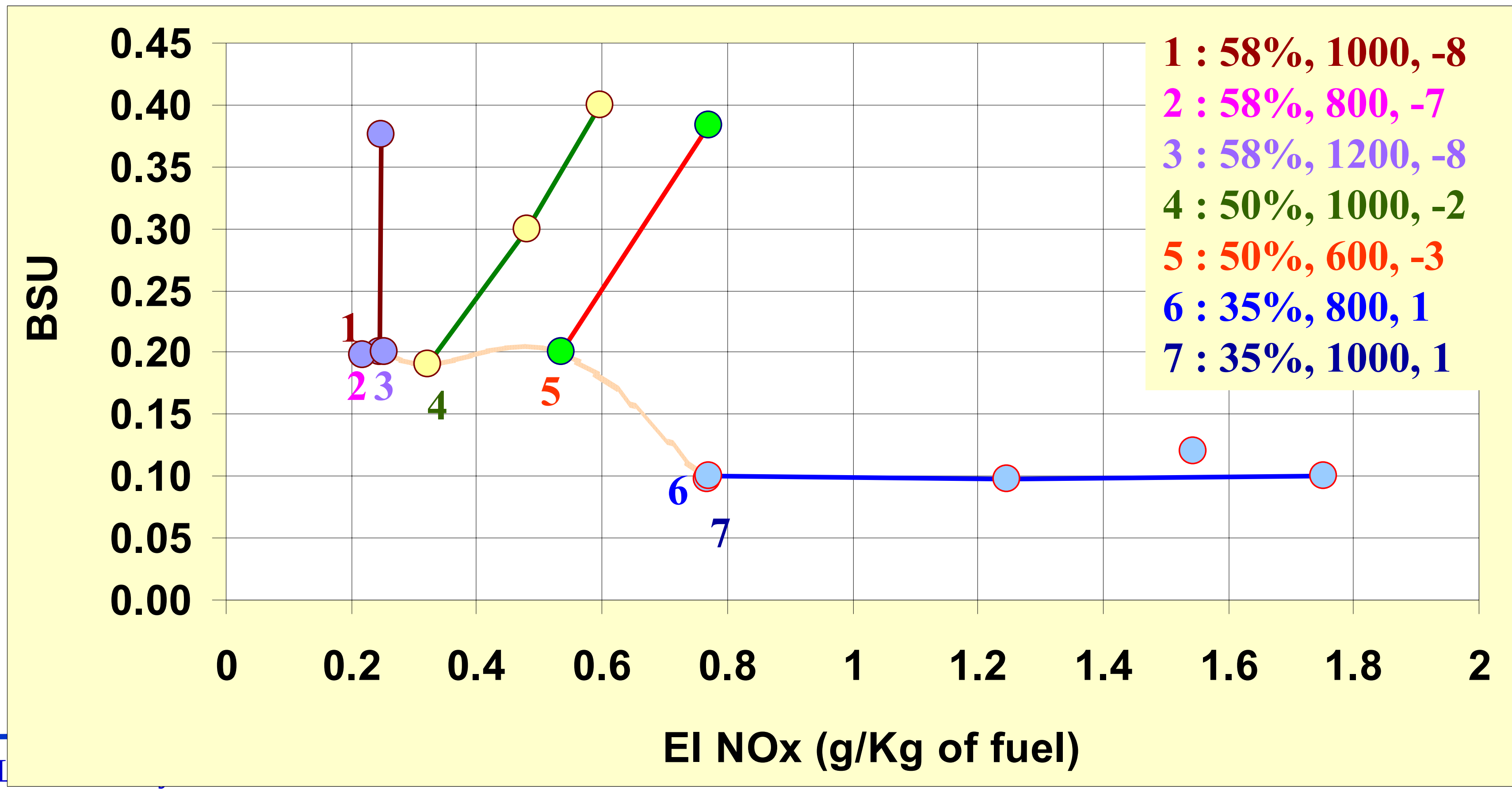


M-L (MISFIRING LINE) POINTS

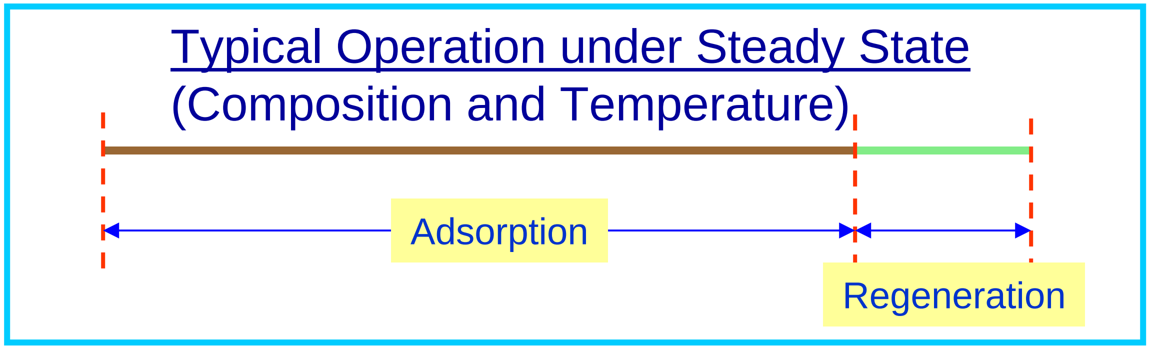


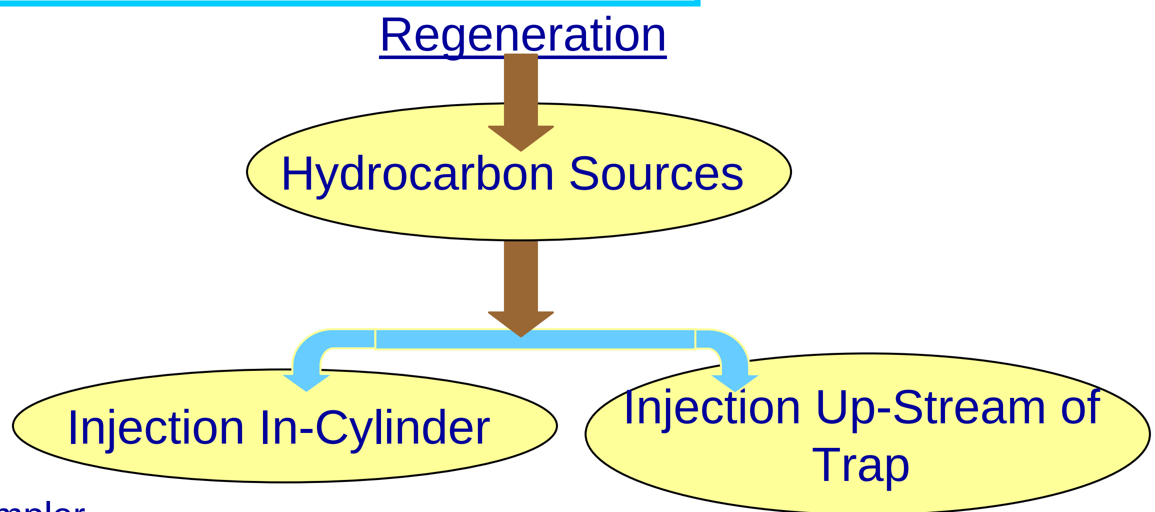






OPERAS for LNT





- Simpler
- Less Cost
- Better Evaporation and Mixing
- Concerns :
  - Partial Oxidation Products
  - Fuel reaching Lube Oil

OPERAS for LNT

Concerns

- Effect of the following species on LNT operation

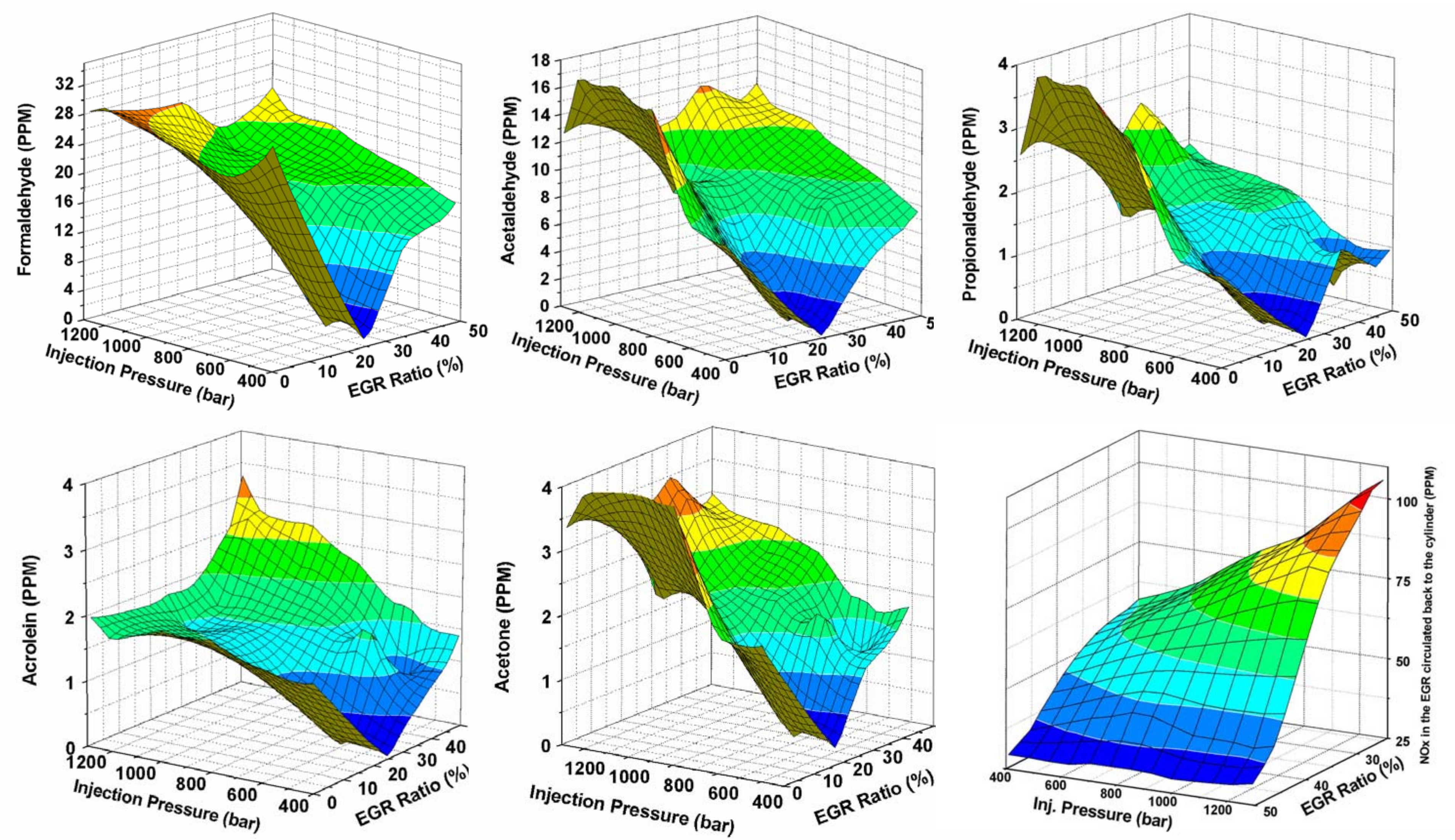
  CO2
  H2O
  RCHO
  S??

- LNT Operation under transient modes

  Cold Starting
  Warming Up
  Hot Acceleration
  Deceleration

- Species generated from lube Oil Addi

Aldehydes Emissions, KP2
LPP:6-7°aTDC

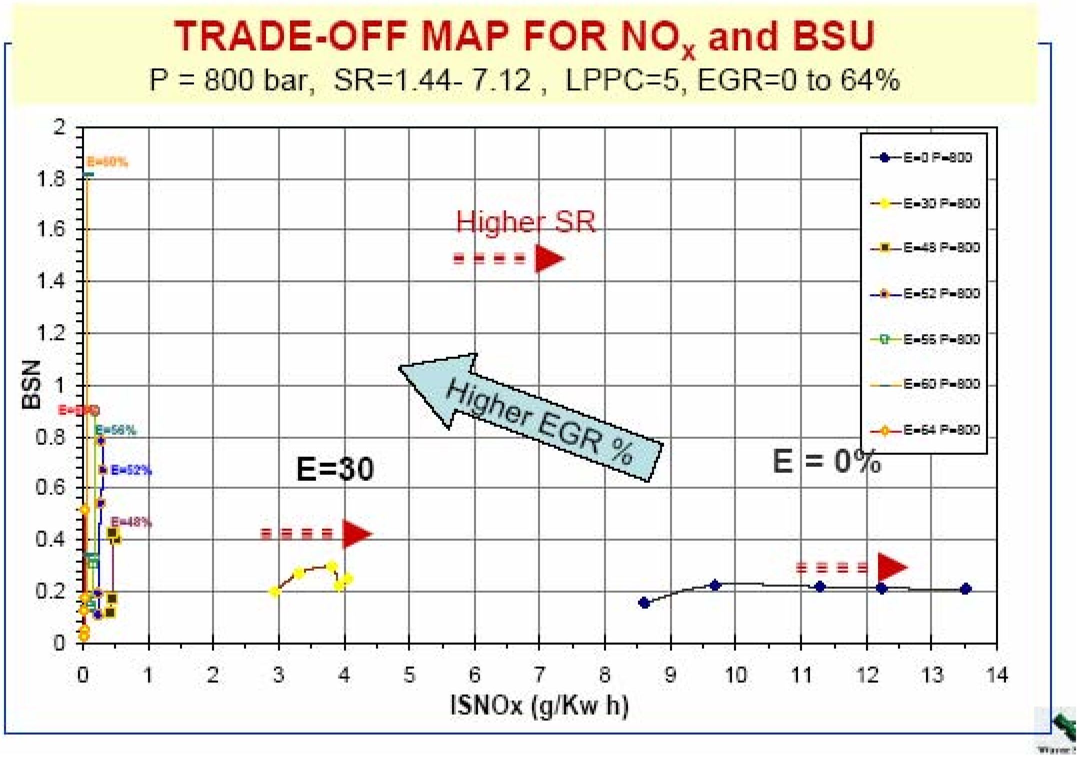


Operating Conditions

- IMEP = 3 Bar
- Engine Speed= 1500 rpm

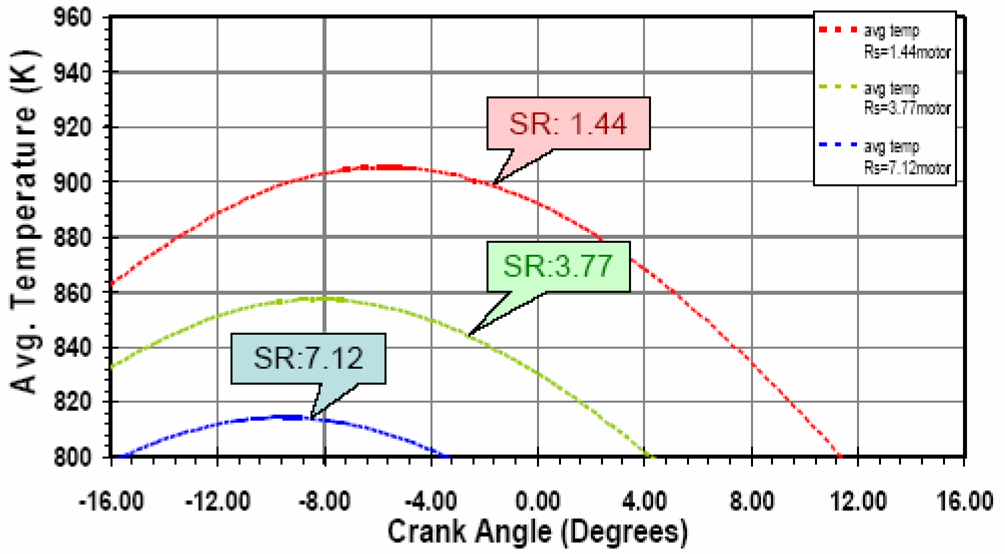
Operating Variables

- Injection Pressure: 600, 800, 1000, 1200 Bar
- EGR Rate: Variable up to misfire limit
- Injection Timing Retard Or Advance for LPPC = 5°aTDC
- Swirl Ratio: Variable 1.44 to 7.12
  -

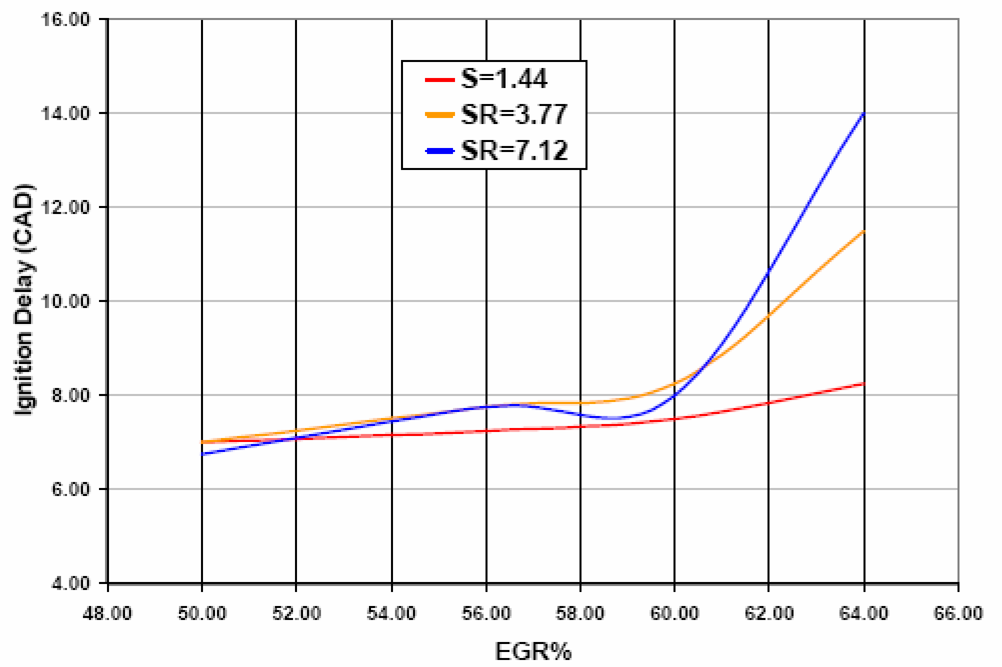


TRADE-OFF MAP FOR NOx and BSU
P = 800 bar, SR=1.44- 7.12 , LPPC=5, EGR=0 to 64%
BSN
ISNOx (g/Kw h)
Higher SR
Higher EGR %
E=30
E = 0%
E=60%
E=56%
E=52%
E=48%
E=0 P=800
E=30 P=800
E=48 P=800
E=52 P=800
E=56 P=800
E=60 P=800
E=64 P=800

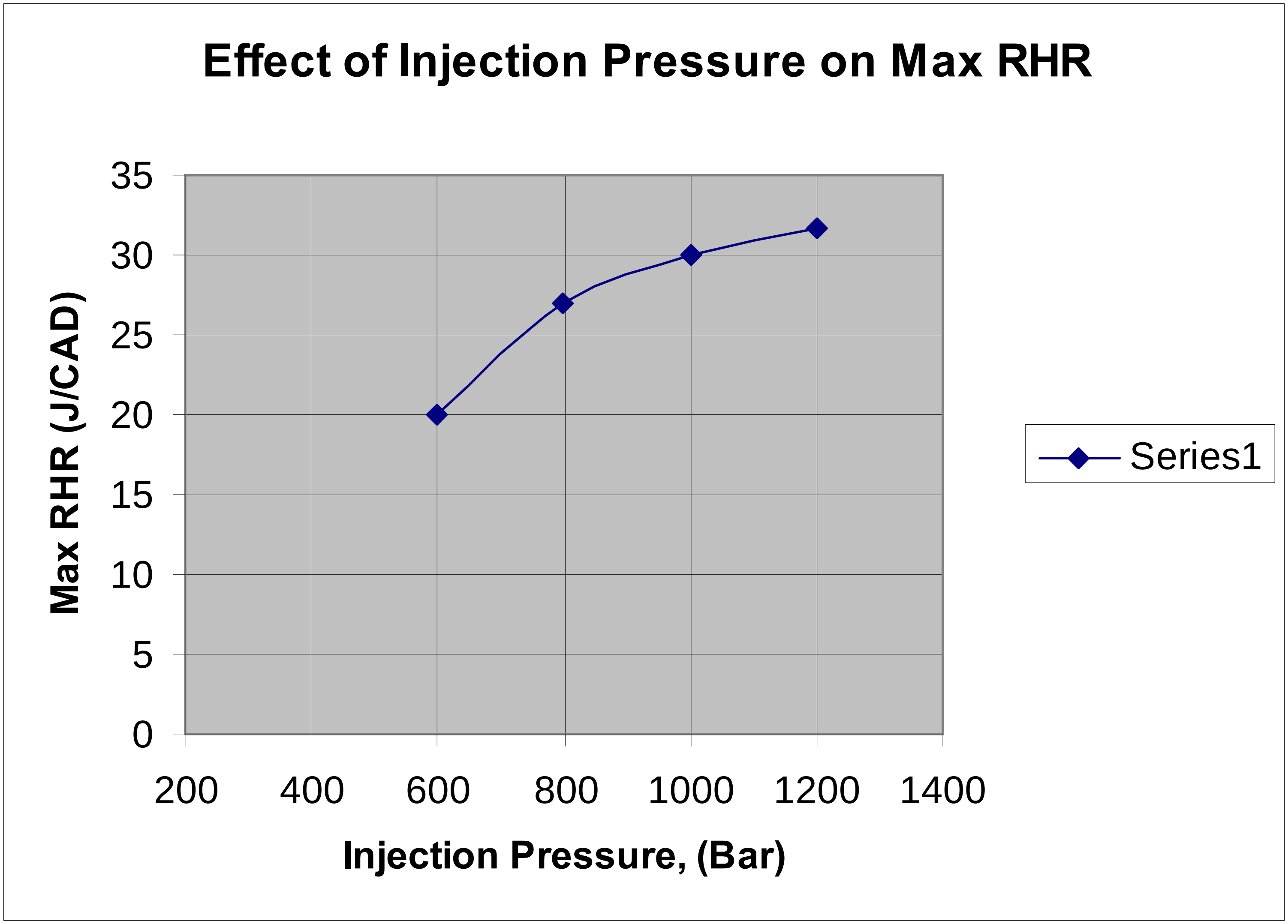
EFFECT OF SWIRL RATIO ON COPRESSION TEMPERATURE



EFFECT OF SR ON I D, 800 Bar

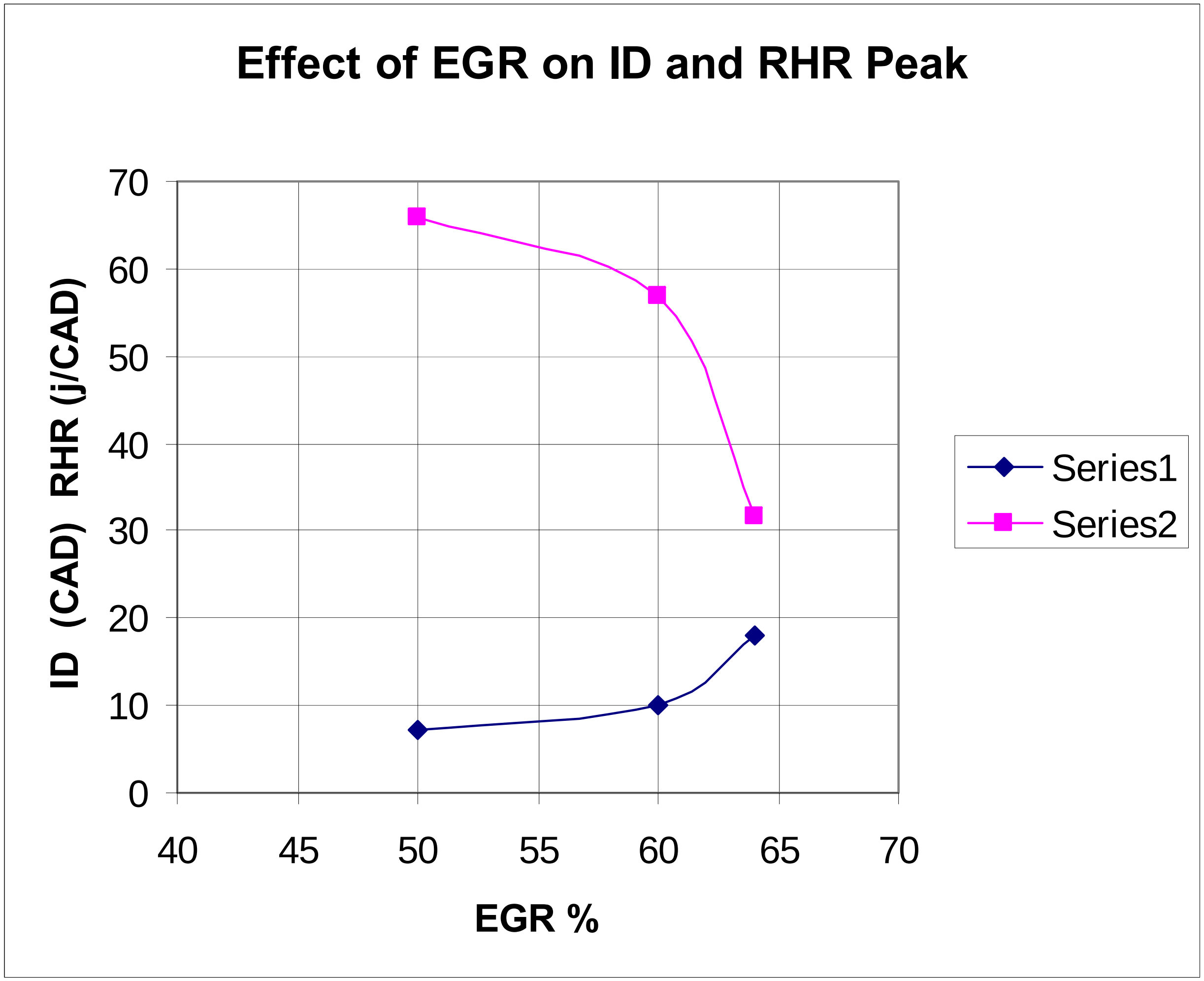


EFFECT OF INJECTION PRESSURE ON MAXIMUM RHR, EGR = 64% LPPC = 5°aTDC

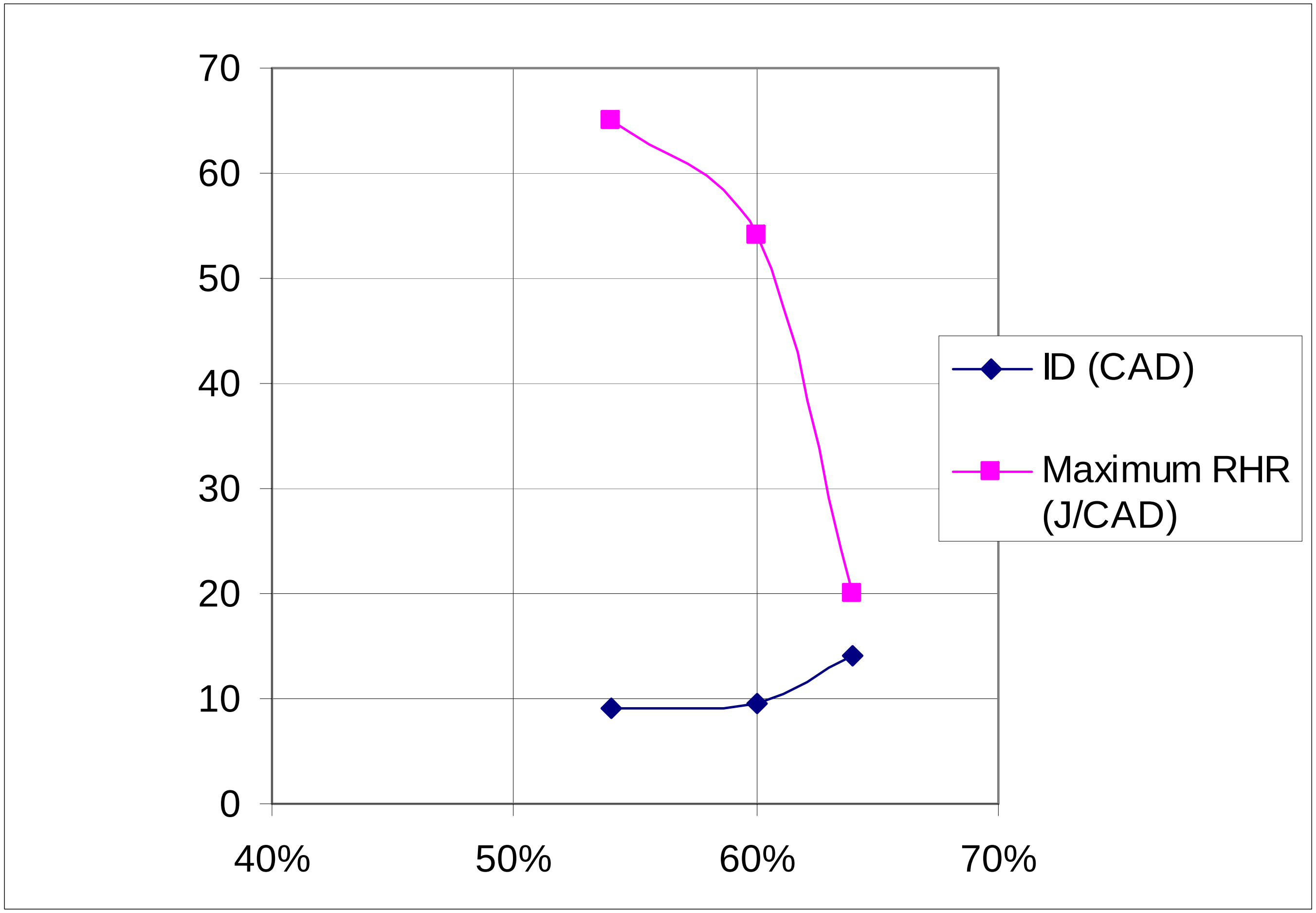


EFFECT OF EGR ON ID AND MAXIMUM RHR

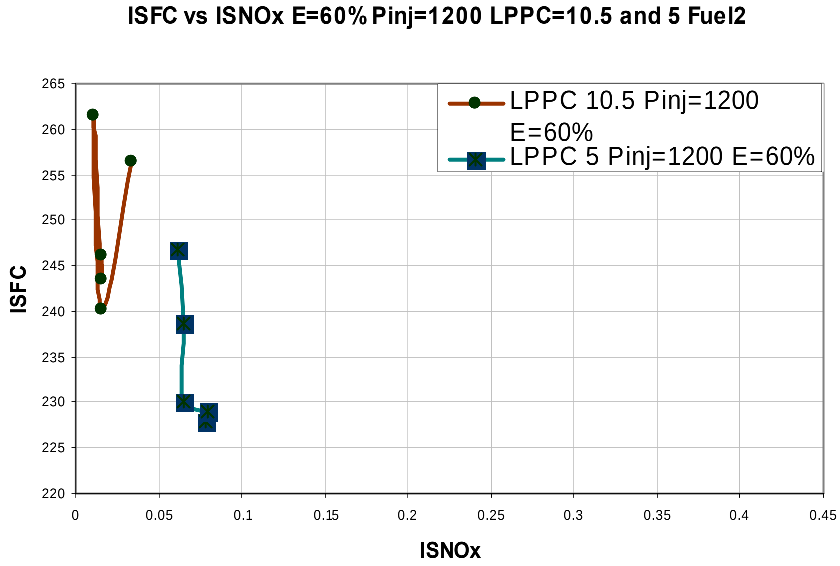
1200 bar, EGR: 50% to 64%, LPPC =5 °aTDC



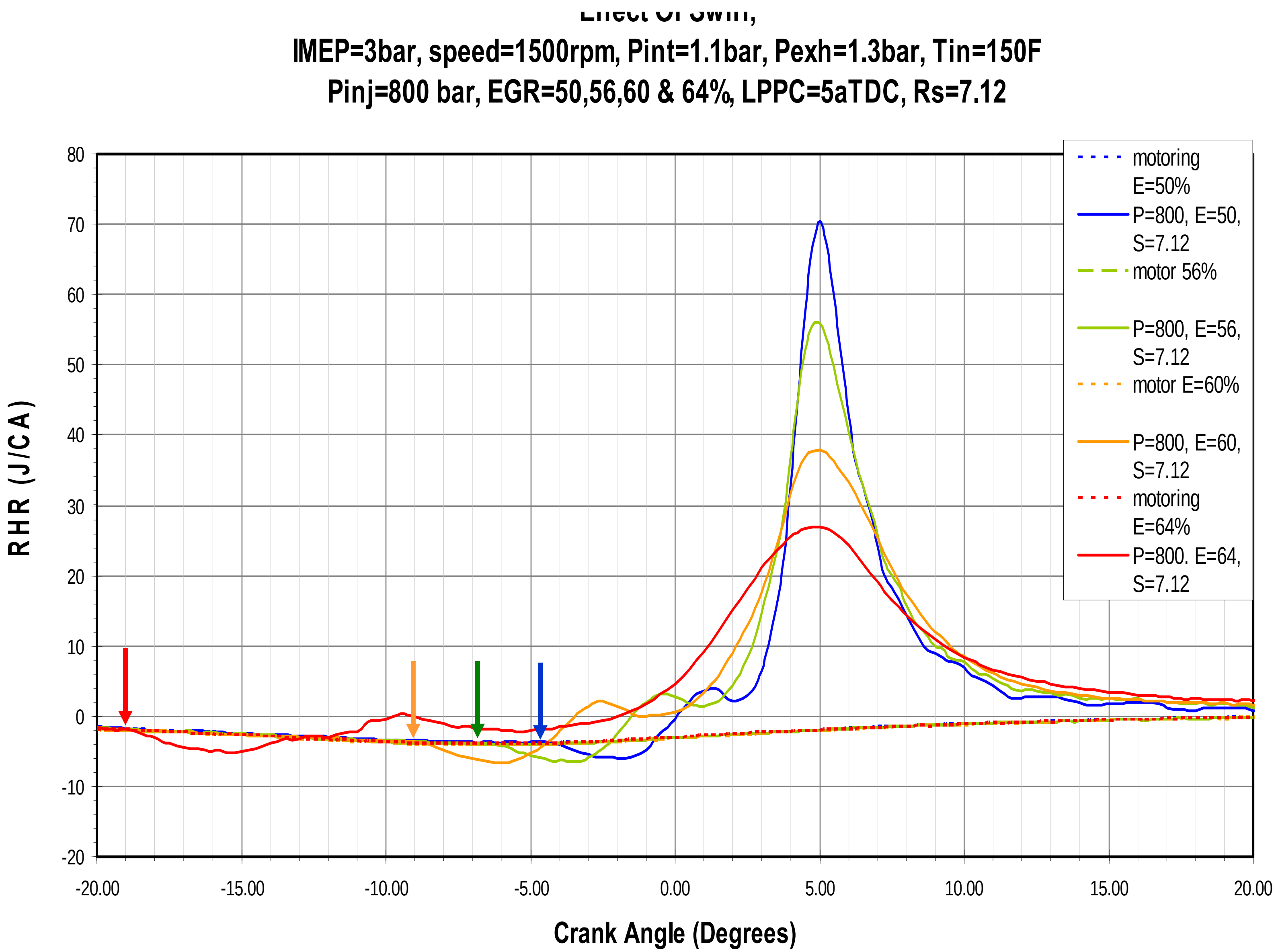
EFFECT OF EGR ON ID AND MAXIMUM RHR
600 bar, EGR: 50% to 64%, LPPC =5 °aTDC



COMPARISON BETWEEN MK AND WSU STRATEGIES



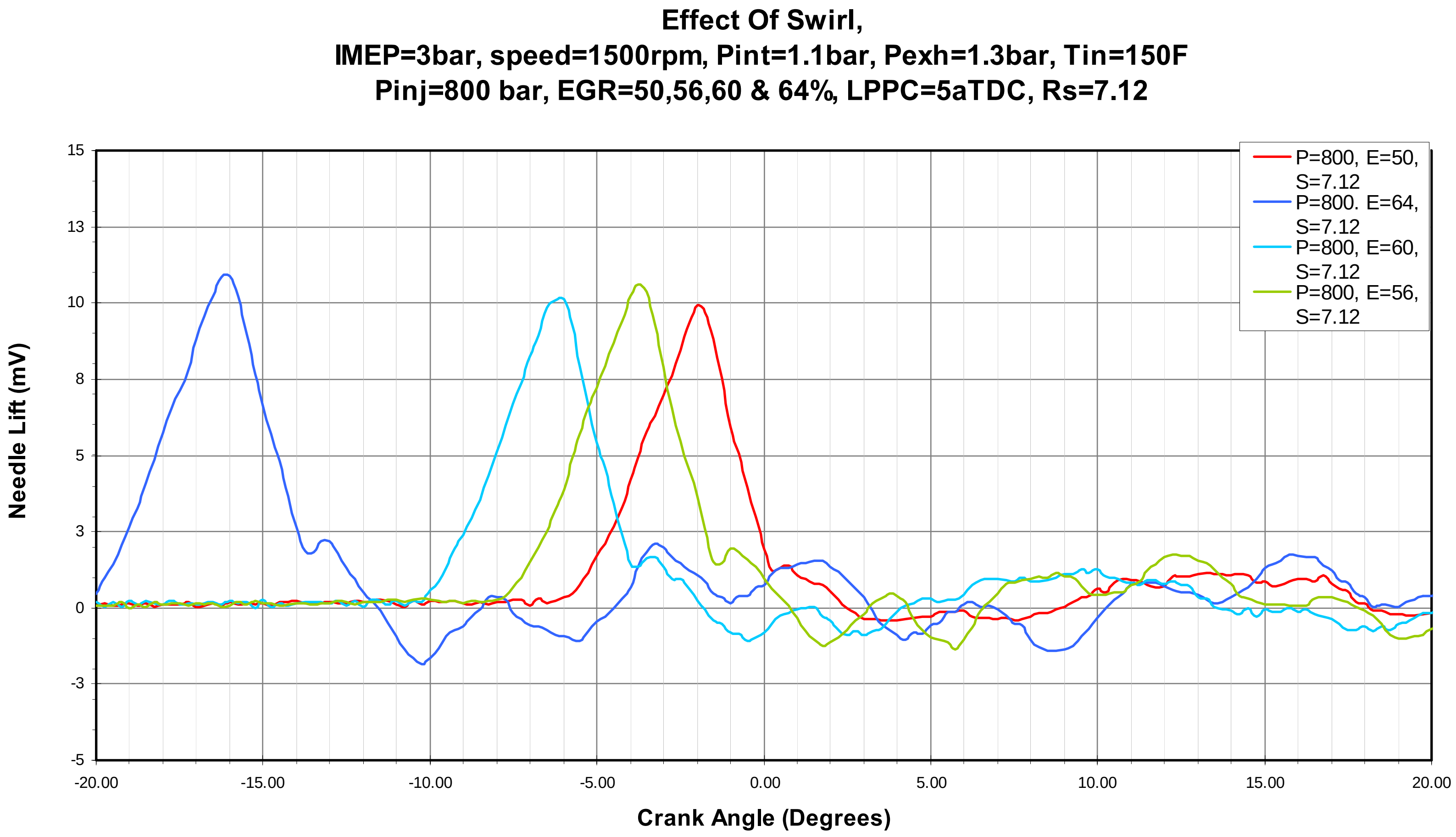
SR=



EFFECT OF EGR%: 50%,56%,60% and 64%

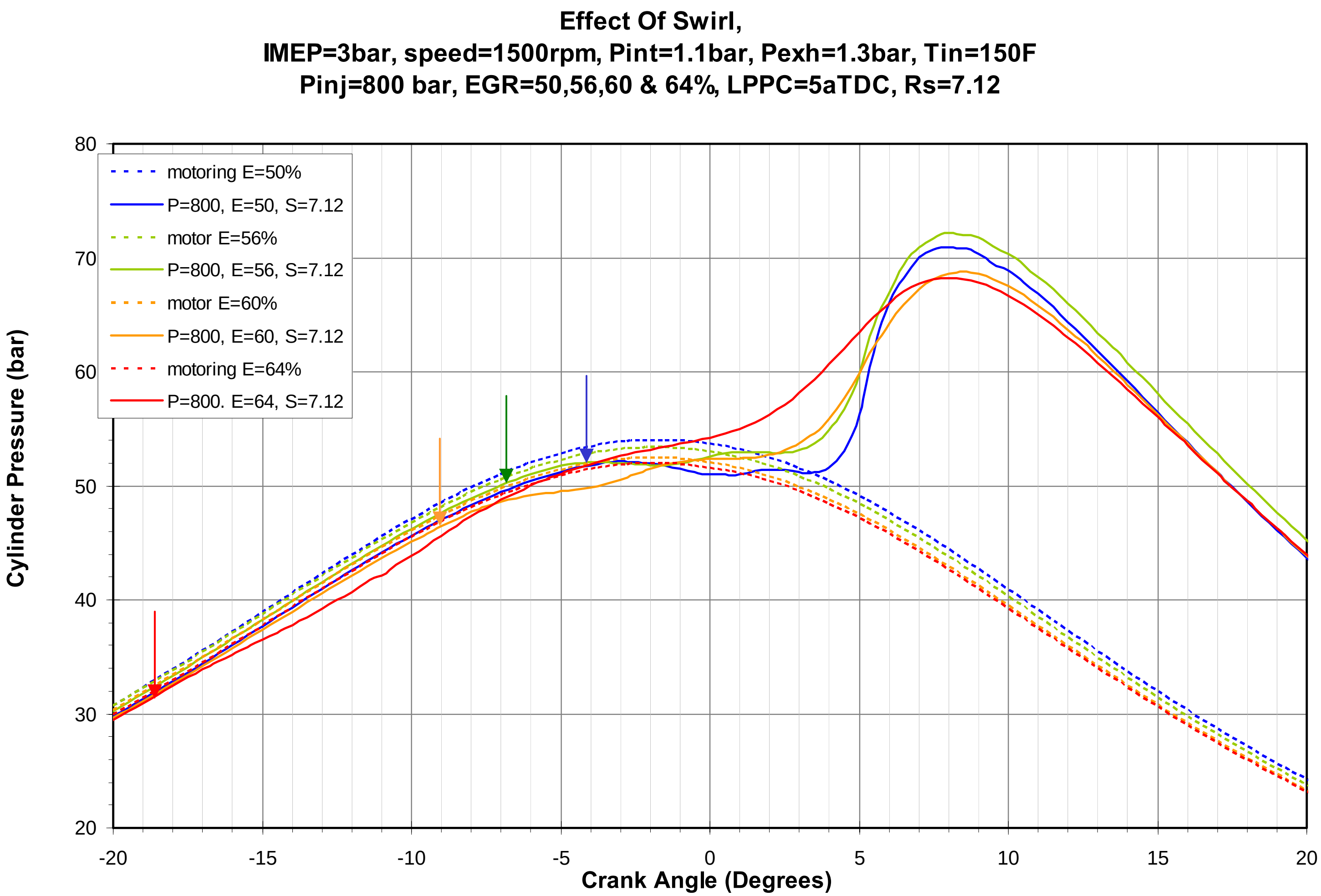
SR: 7.12

EFFECT OF EGR%: 50%,56%,60% and 64%
SR: 7.12



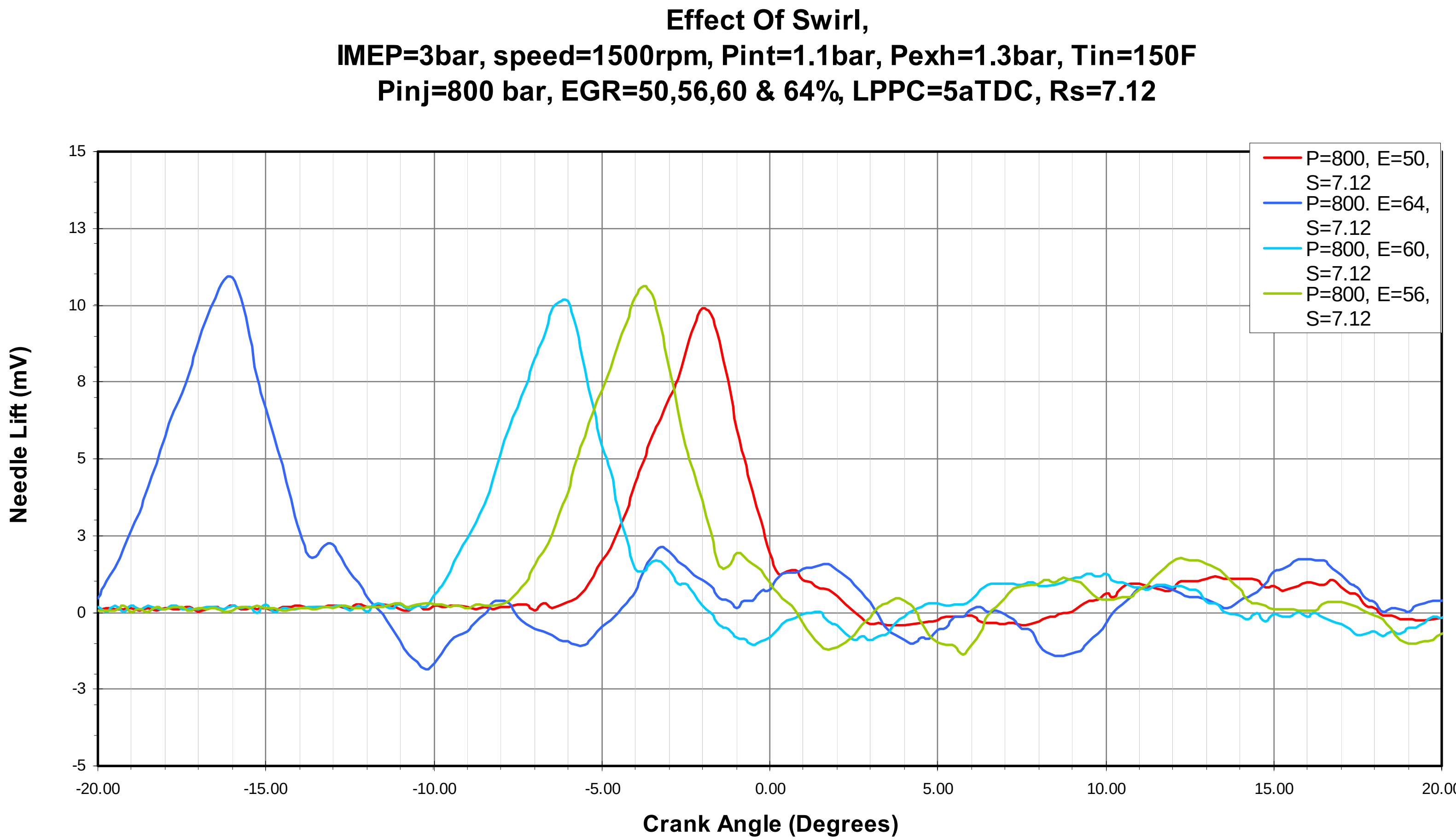
EFFECT OF EGR%: 50%,56%,60% and 64%

SR: 7.12



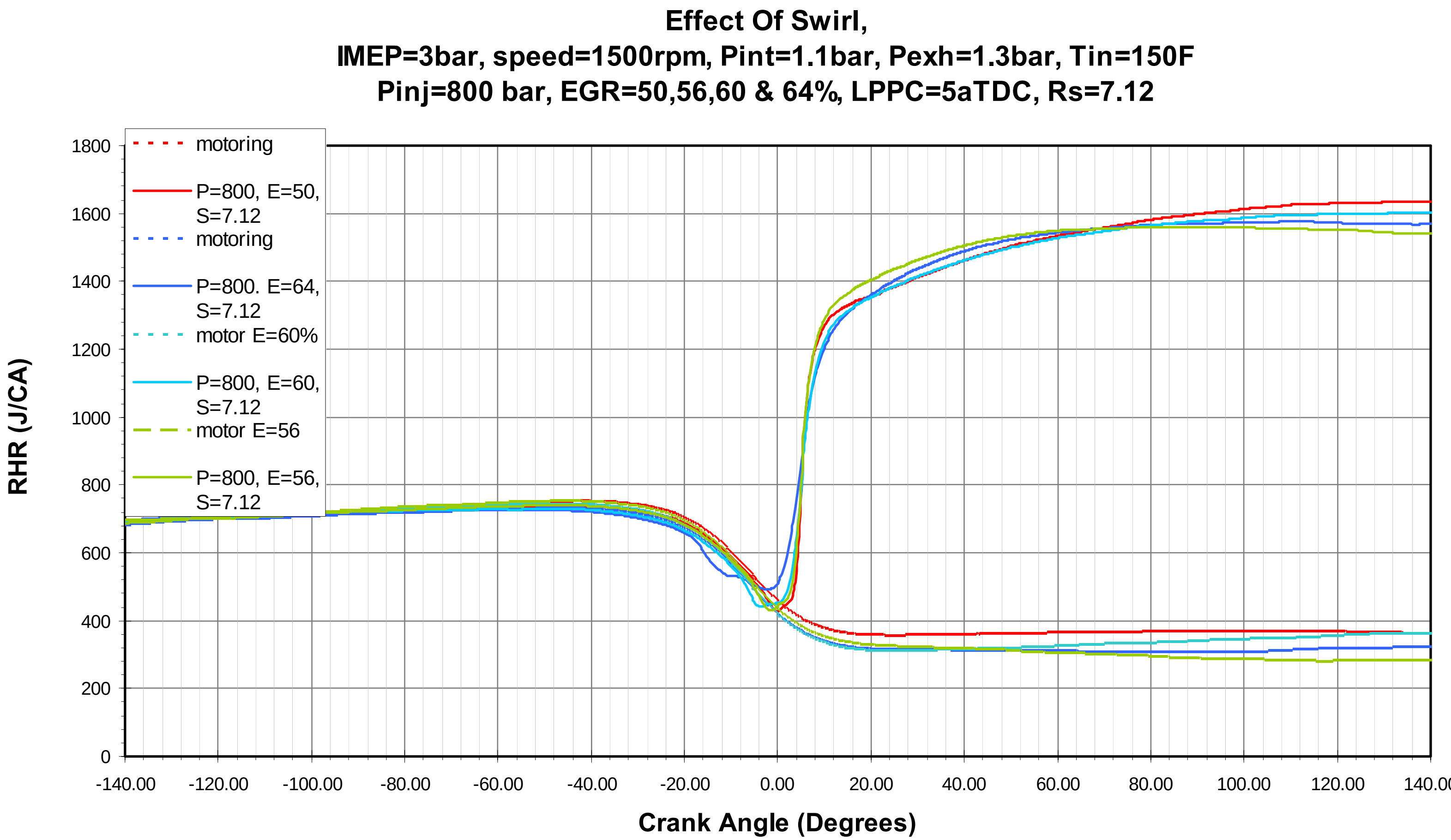
EFFECT OF EGR%: 50%,56%,60% and 64%

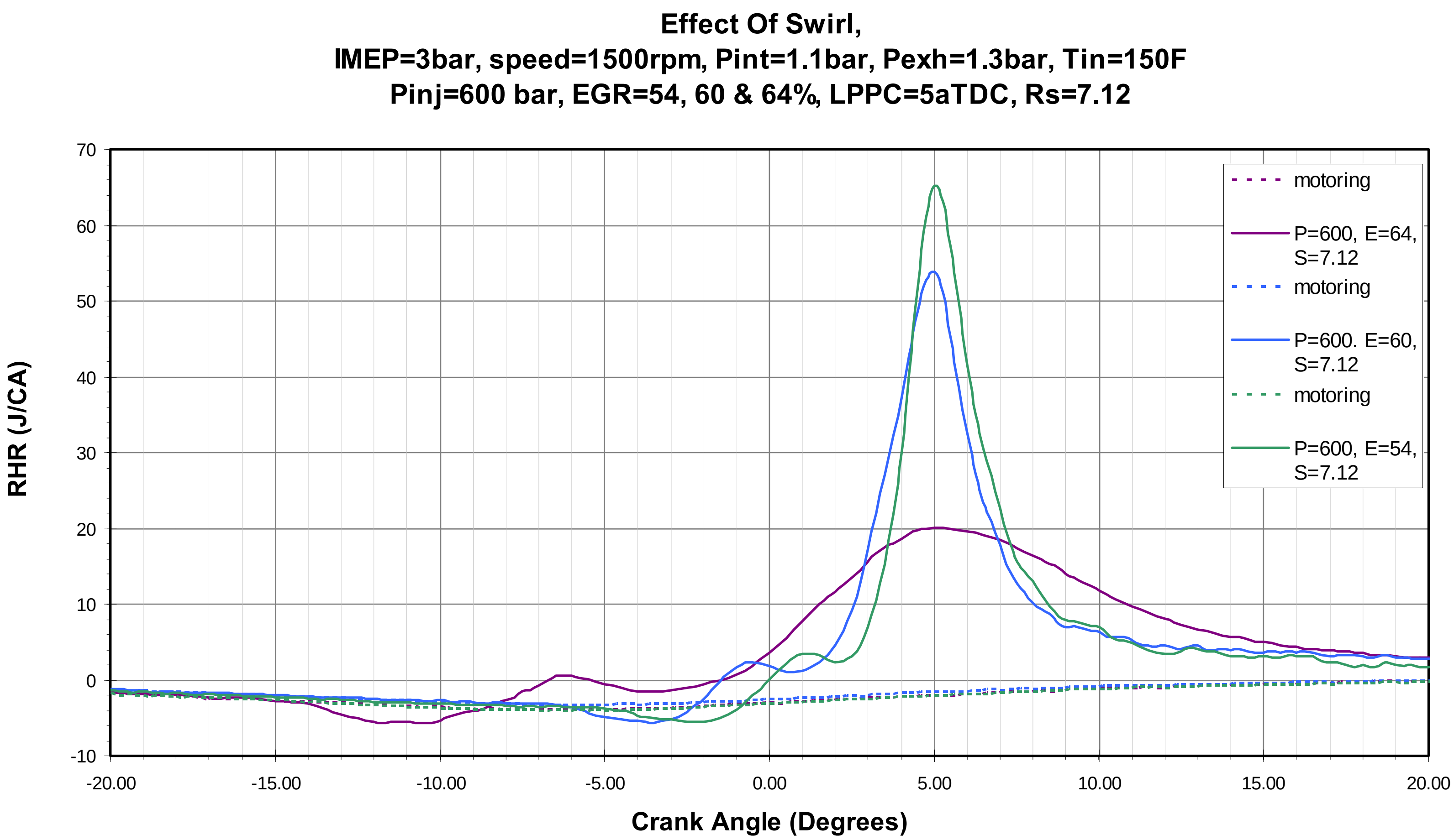
SR: 7.12



EFFECT OF EGR%: 50%,56%,60% and 64%

SR: 7.12

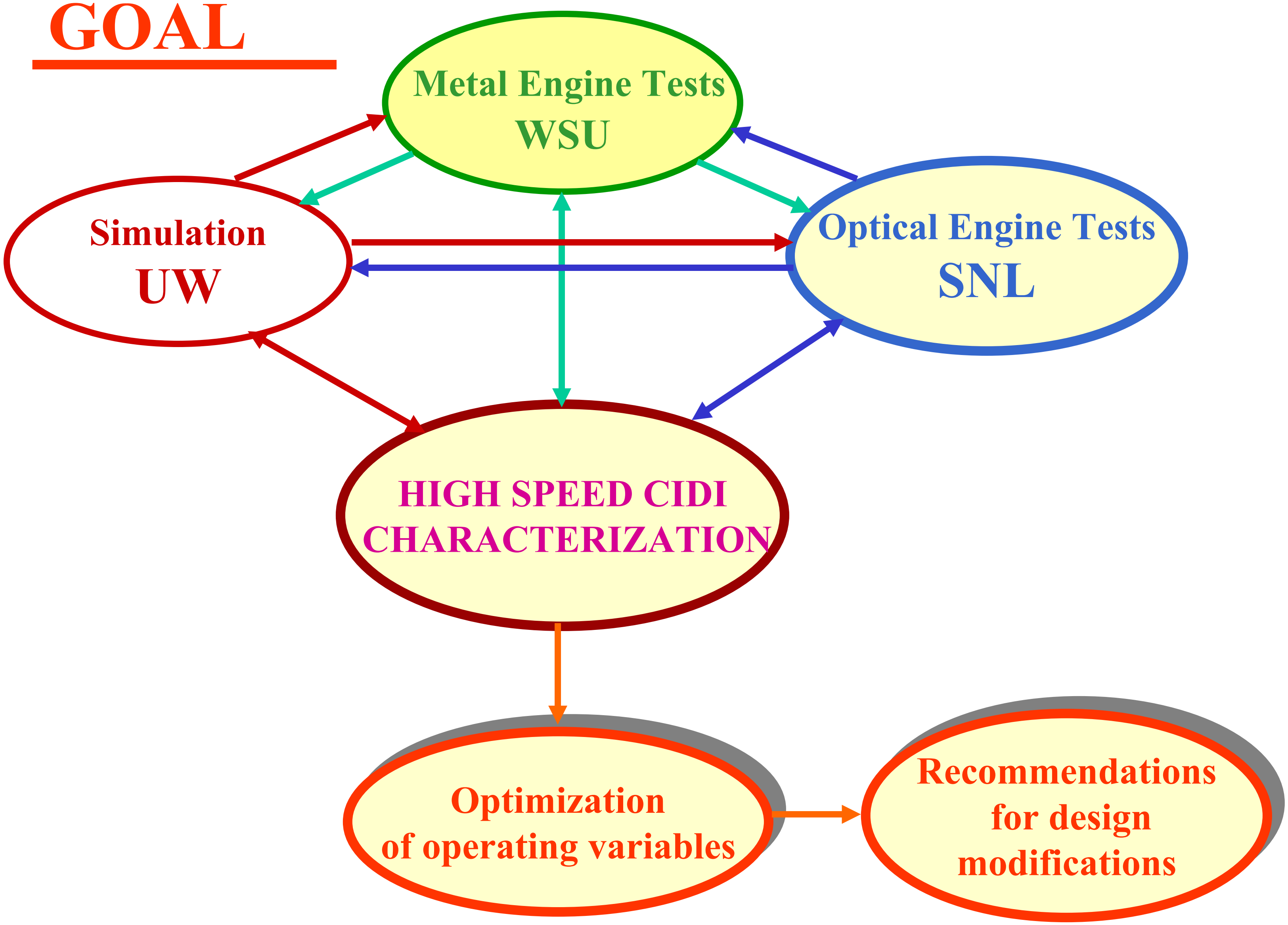



Effect Of Swirl,
IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F
Pinj=600 bar, EGR=54, 60 & 64%, LPPC=5aTDC, Rs=7.12
RHR (J/CA)
70
60
50
40
30
20
10
0
-10
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
Crank Angle (Degrees)
motoring
P=600, E=64, S=7.12
motoring
P=600. E=60, S=7.12
motoring
P=600, E=54, S=7.12

Outline

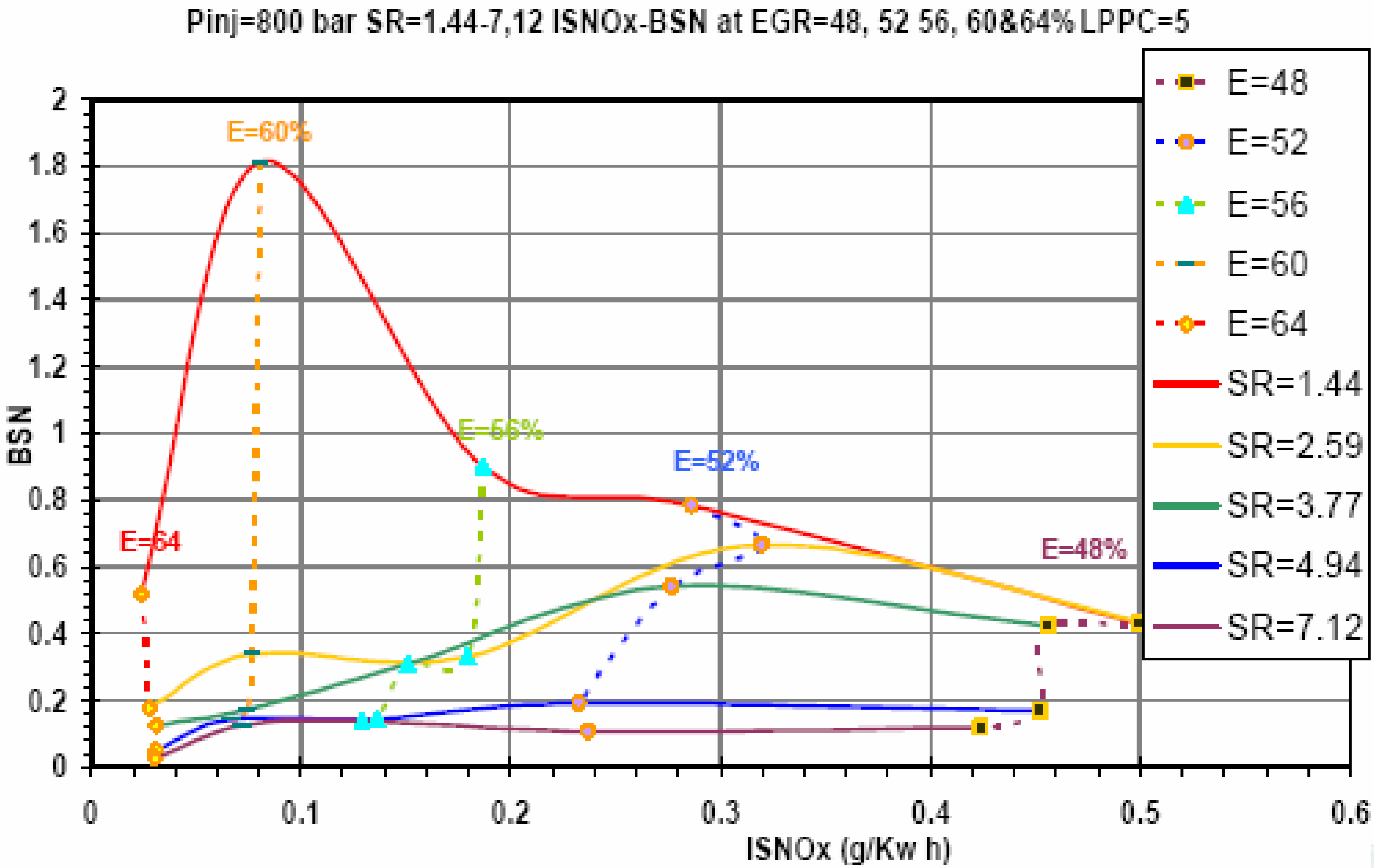
- Introduction
- Goal
- Summary of previous Investigations
- Scope
- Effect of
    1. EGR
    2. Swirl Ratio
    3. Injection Pressure
- Conclusions
- Recommendations

GOAL



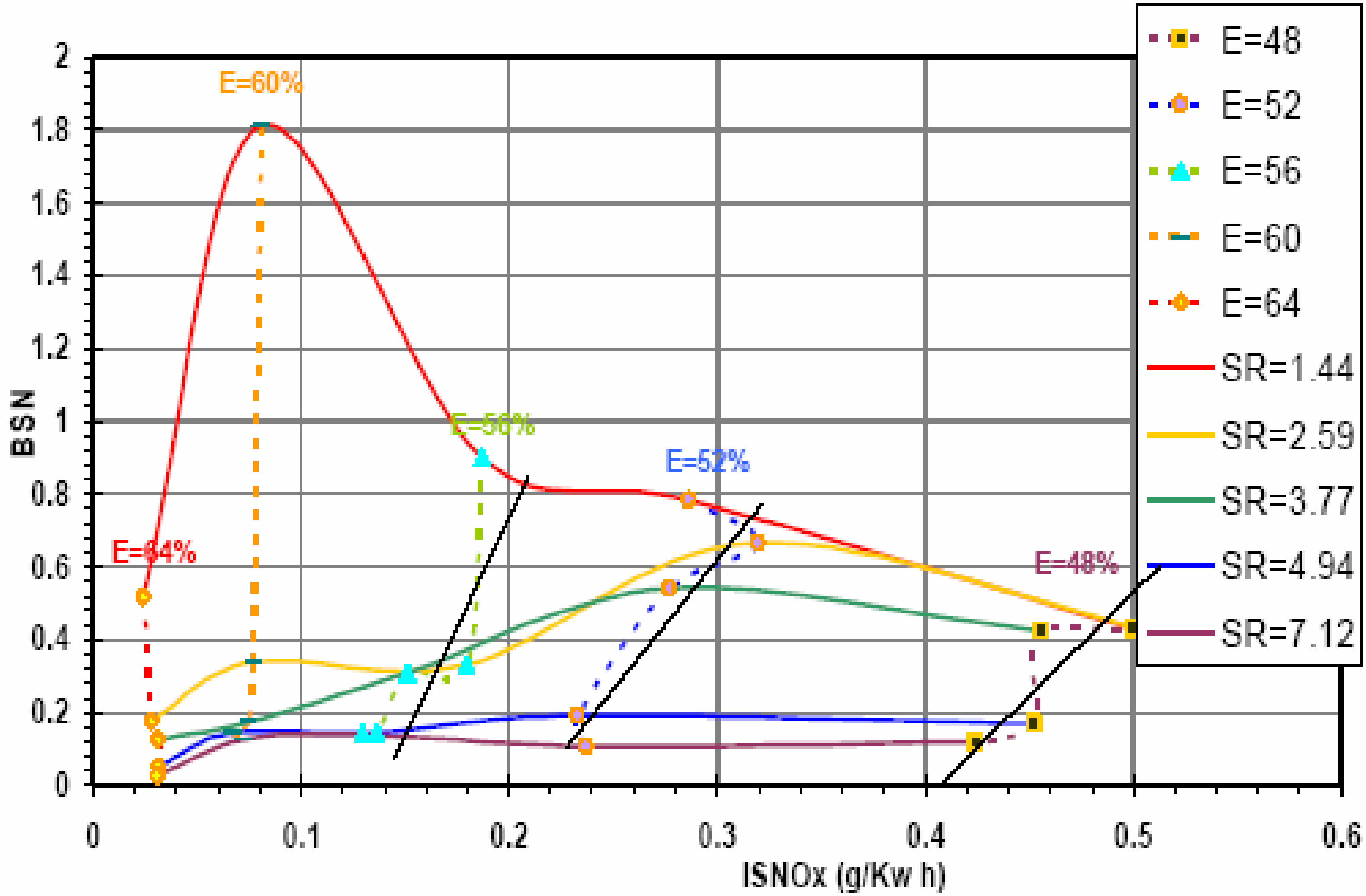
Metal Engine Tests
WSU
Simulation
UW
Optical Engine Tests
SNL
HIGH SPEED CIDI
CHARACTERIZATION
Optimization
of operating variables
Recommendations
for design
modifications

TRADE-OFF BETWEEN $ISNO_X$ AND BSN
EFFECT OF SWIRL RATIO

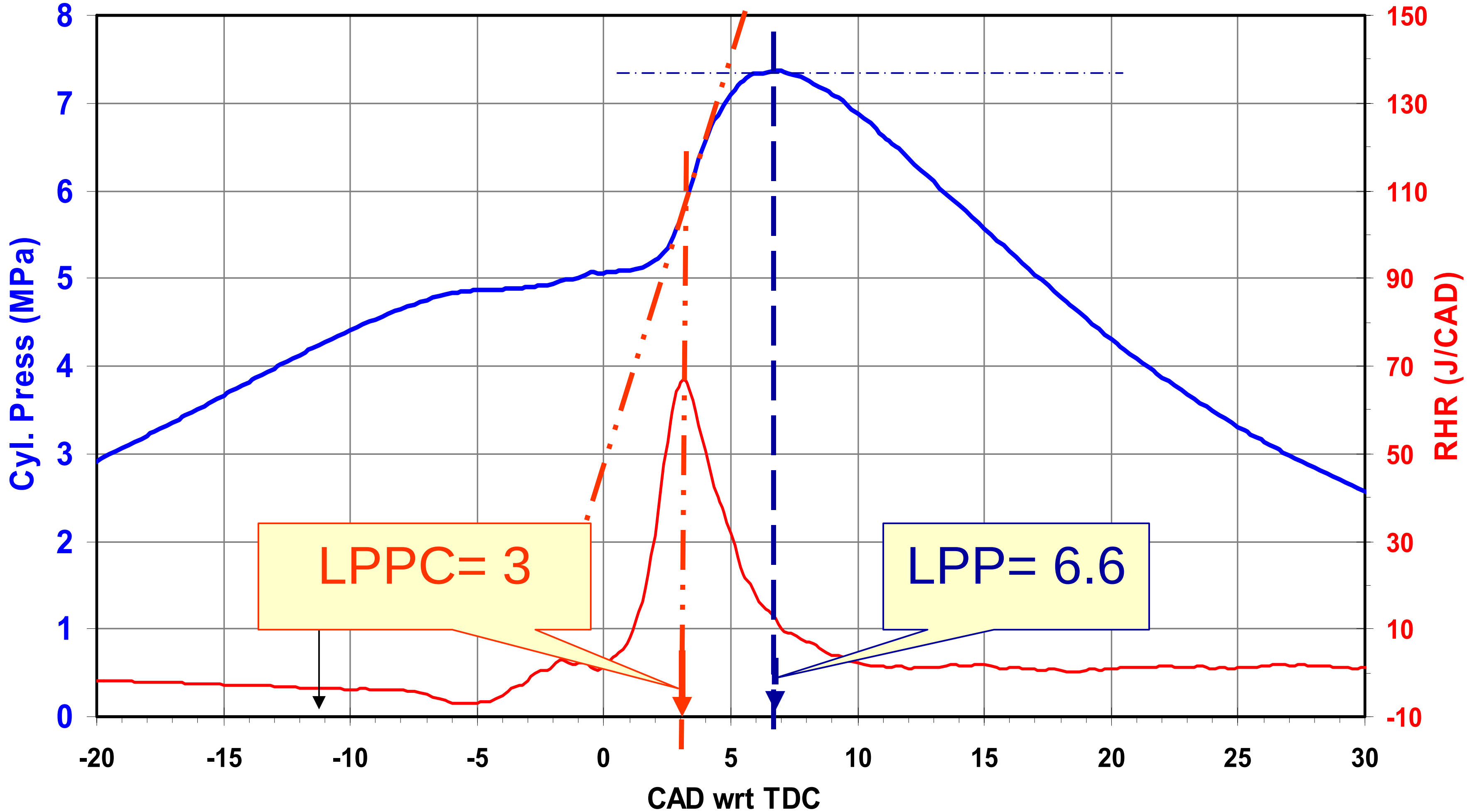


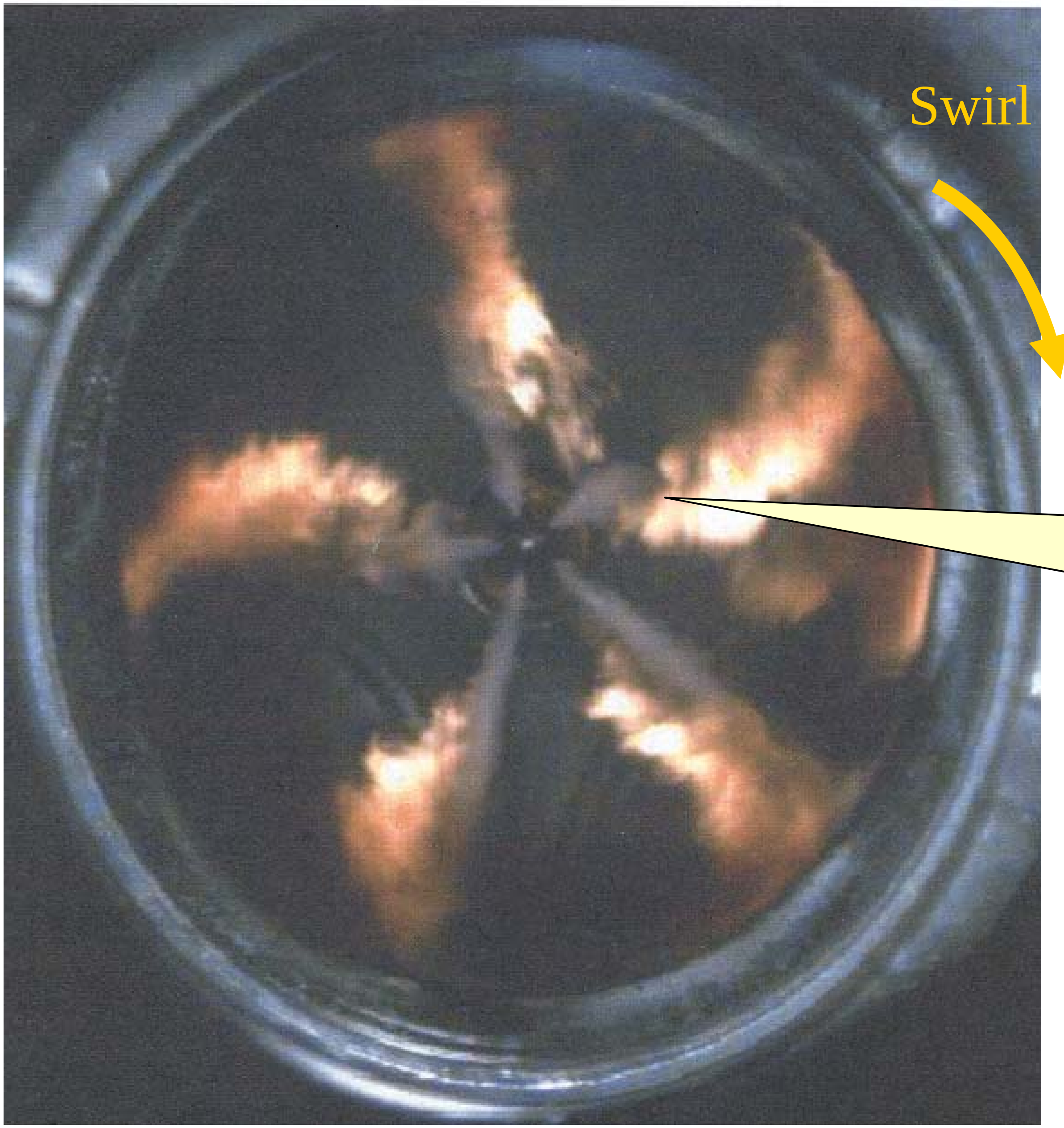
TRADE-OFF MAP FOR NO_x and BSU

P = 800 bar, SR=1.44- 7.12 , LPPC=5, EGR=48, 52, 56, 60 & 64%



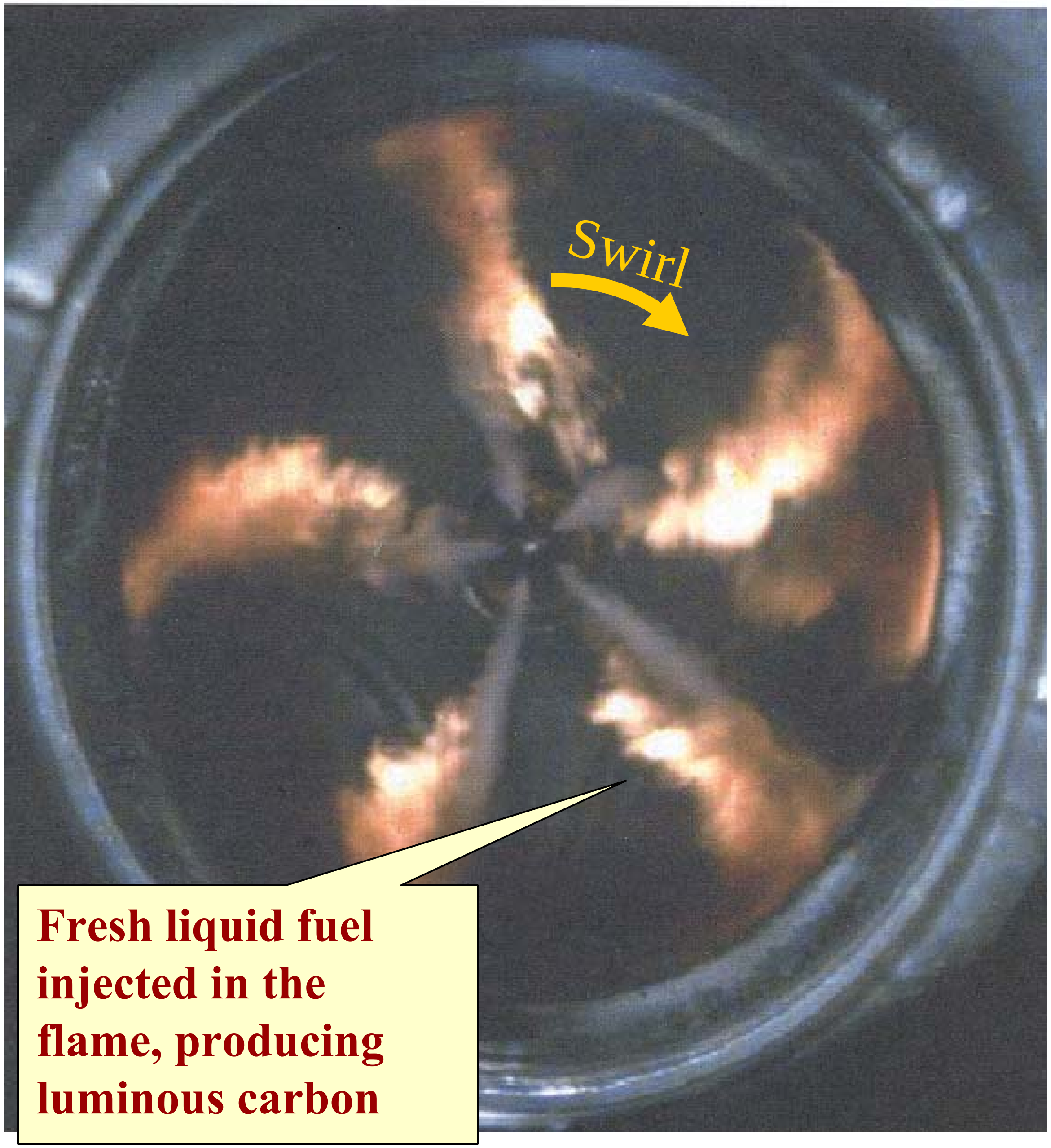
Sample cylinder pressure & RHR traces
Reference Timing Points





SPRAY COMBUSTION IN SWIRLING AIR

Fresh liquid fuel is injected in the flame, producing luminous carbon



CONVENTIONAL DIESEL COMBUSTION

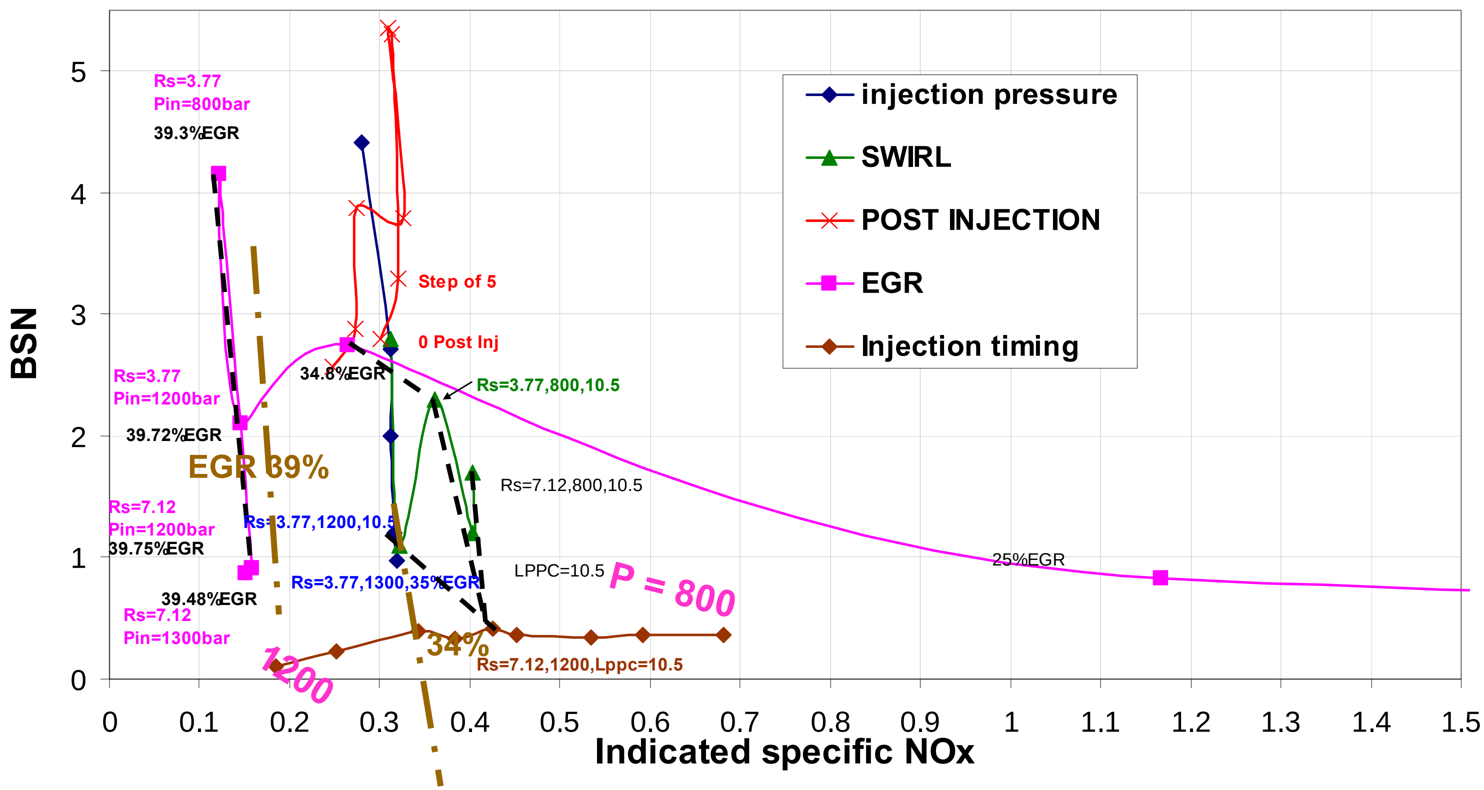
- Heterogeneous Charge of liquid fuel, fuel vapor, air, CO_2, H_2O, N_2,...
- Soot is formed from the liquid, gas phase, rich premixed charge and diffusion flames.
- Soot may be oxidized later under proper temperature, and mixing conditions.
- NO is formed from the stoichiometric or lean parts of the charge.

Effect of Injection Pressure & EGR

•IMEP = 6 bar
•1500 RPM

Inj Timing = LPPC 10.5
Variable EGR = 34 to 39 %

SR= 3.77



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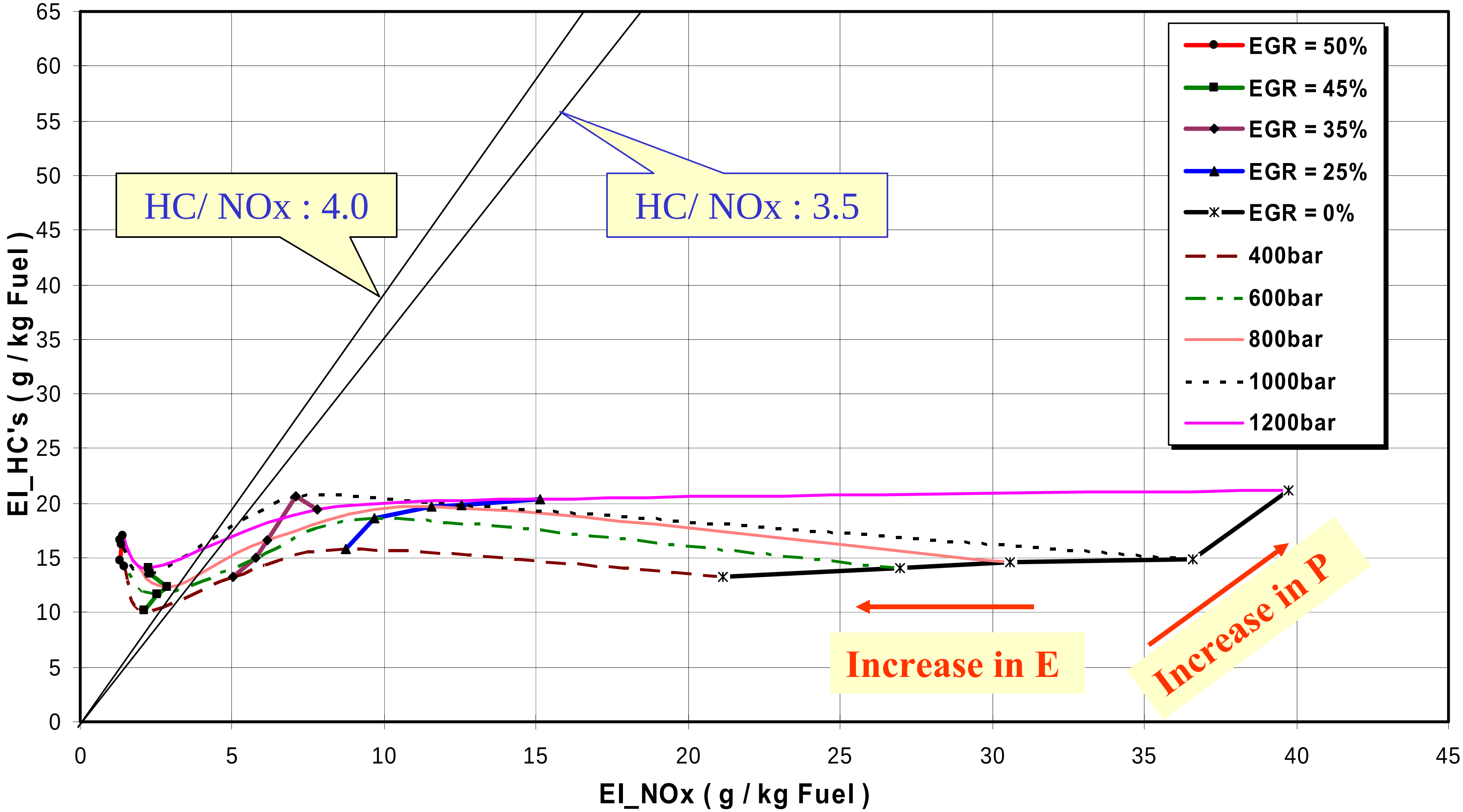
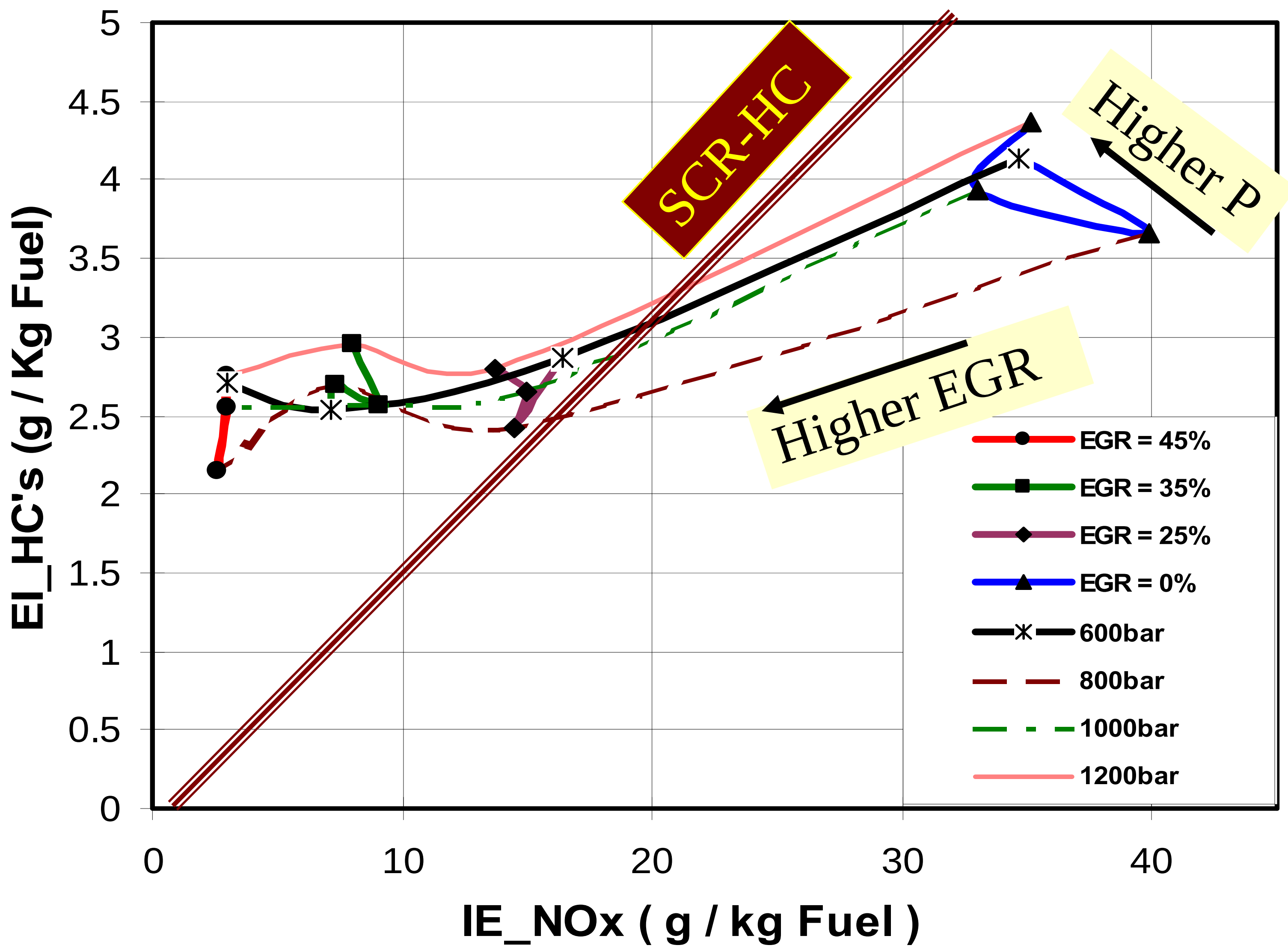
OPERAS FOR PROPER [NO/HC] FOR SCR OPERATION

(KP2 , 320 MINISAC)

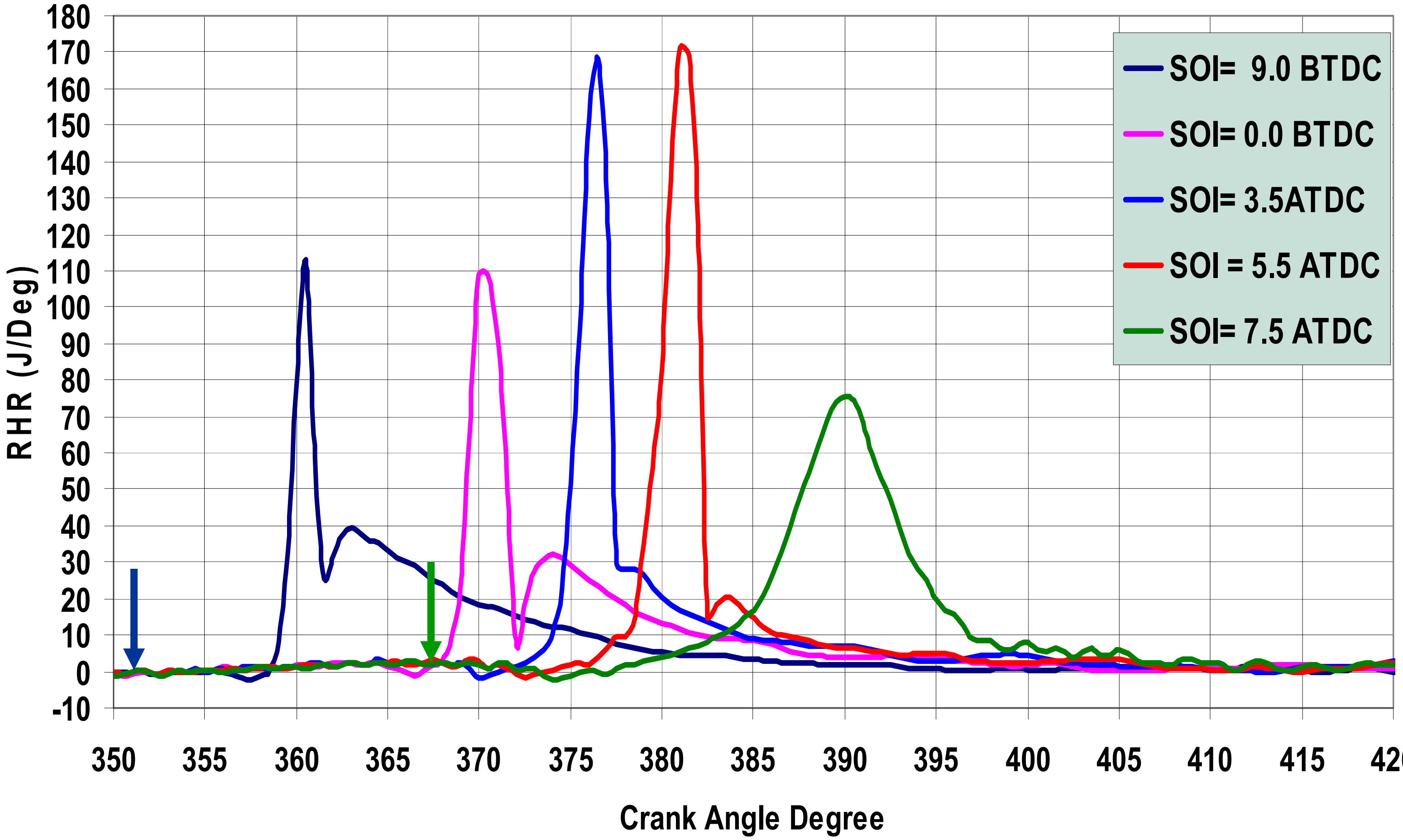


OPERAS FOR PROPER [NO/HC] FOR SCR OPERATION

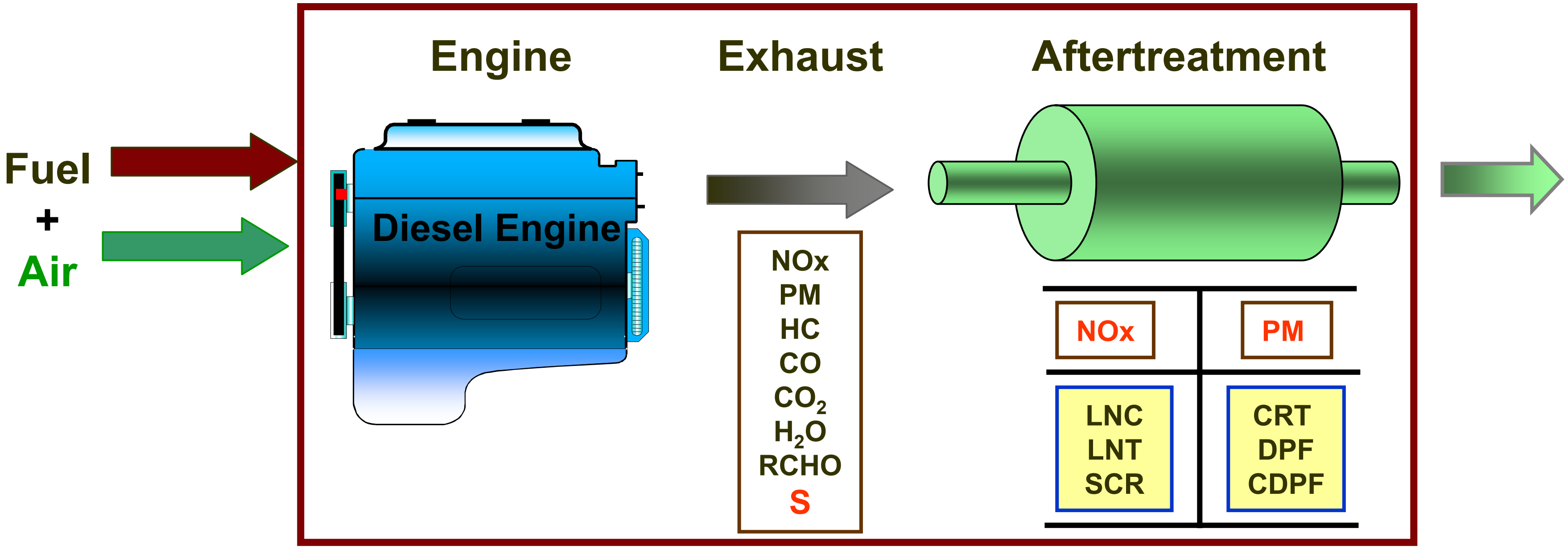


EFFECT OF INJECTION TIMING ON RHR
WSU 1-CYLINDER ENGINE

Engine Speed:2000rpm,IMEP=7bar,0%EGR,1200bar



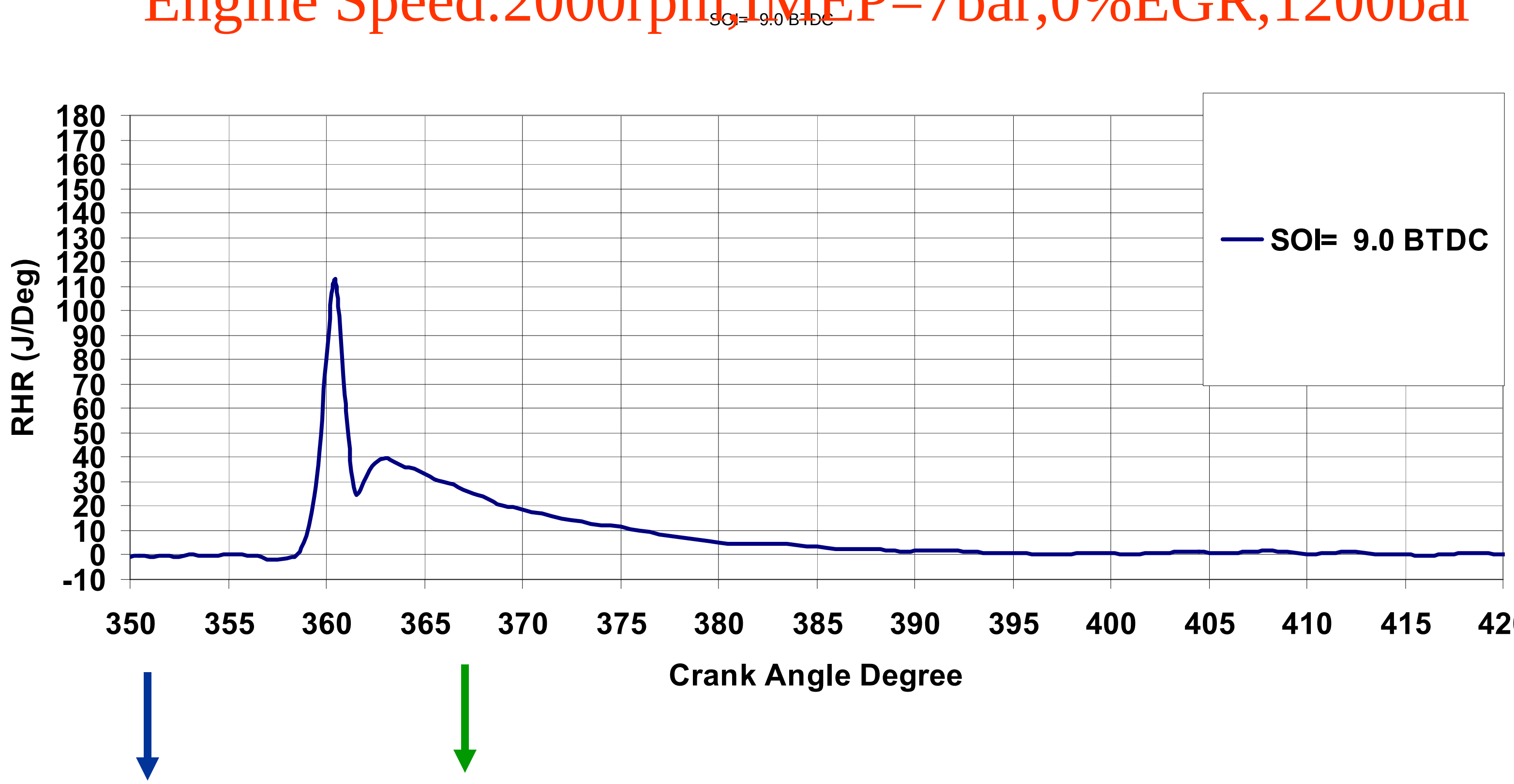
SYSTEM APPROACH



Can the engine management produce the most suitable OPERAS for the after treatment devices ?

EFFECT OF INJECTION TIMING ON RHR
WSU 1-CYLINDER ENGINE

Engine Speed:2000rpm,IMEP=7bar,0%EGR,1200bar



TESTS MATRIX

Nozzles : 430 VCO, 390 Mini-Sac, **320 Mini-Sac**

Test Points:

		RPM	IMEP(Bar)	MAP(Bar)
	KP1	900	1.2	1.0
	KP2	1500	3.0	1.2
	KP3	2000	5.0	1.4
MK EVALUATION	KPM	2000	7.0	1.4

Injection Pressures: 400, 600, 800, 1000, 1200 Bar

Injection Modes: **Main,** Pilot-Main, Main-Post

EGR ratios: 0%, 25%, 35%, 40%, 45%, 50%, 55%

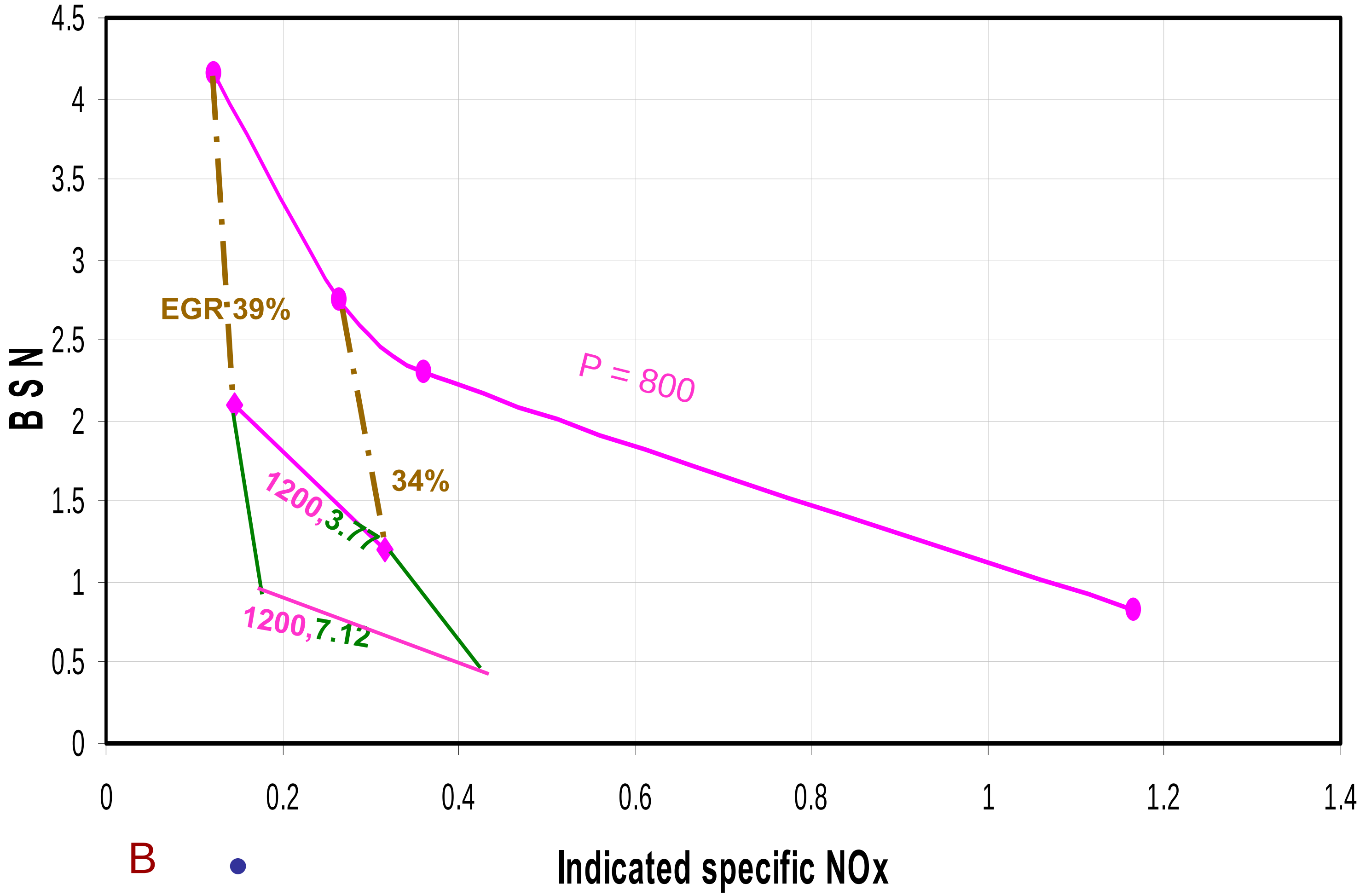
Swirl Ratios: 1.44 – 3.15

Effect of Swirl

•IMEP = 6 bar
•1500 RPM

Inj Timing = LPPC 10.5
Variable EGR = 34 to 39 %

SR= 3.77 to 7.12



MK CONCEPT

SAE TECHNICAL PAPER SERIES

2001-01-0200

Ultra-Clean Combustion Technology Combining a Low-Temperature and Premixed Combustion Concept for Meeting Future Emission Standards

Shuji Kimura, Osamu Aoki, Yasuhisa Kitahara and Eiji Aiyoshizawa
Nissan Motor CO., LTD.

Reprinted From: In-Cylinder Diesel Particulate and NOx Control 2001 (SP-1592)
and
Homogeneous Charge Compression Ignition (HCCI) Combustion (SP-1623)

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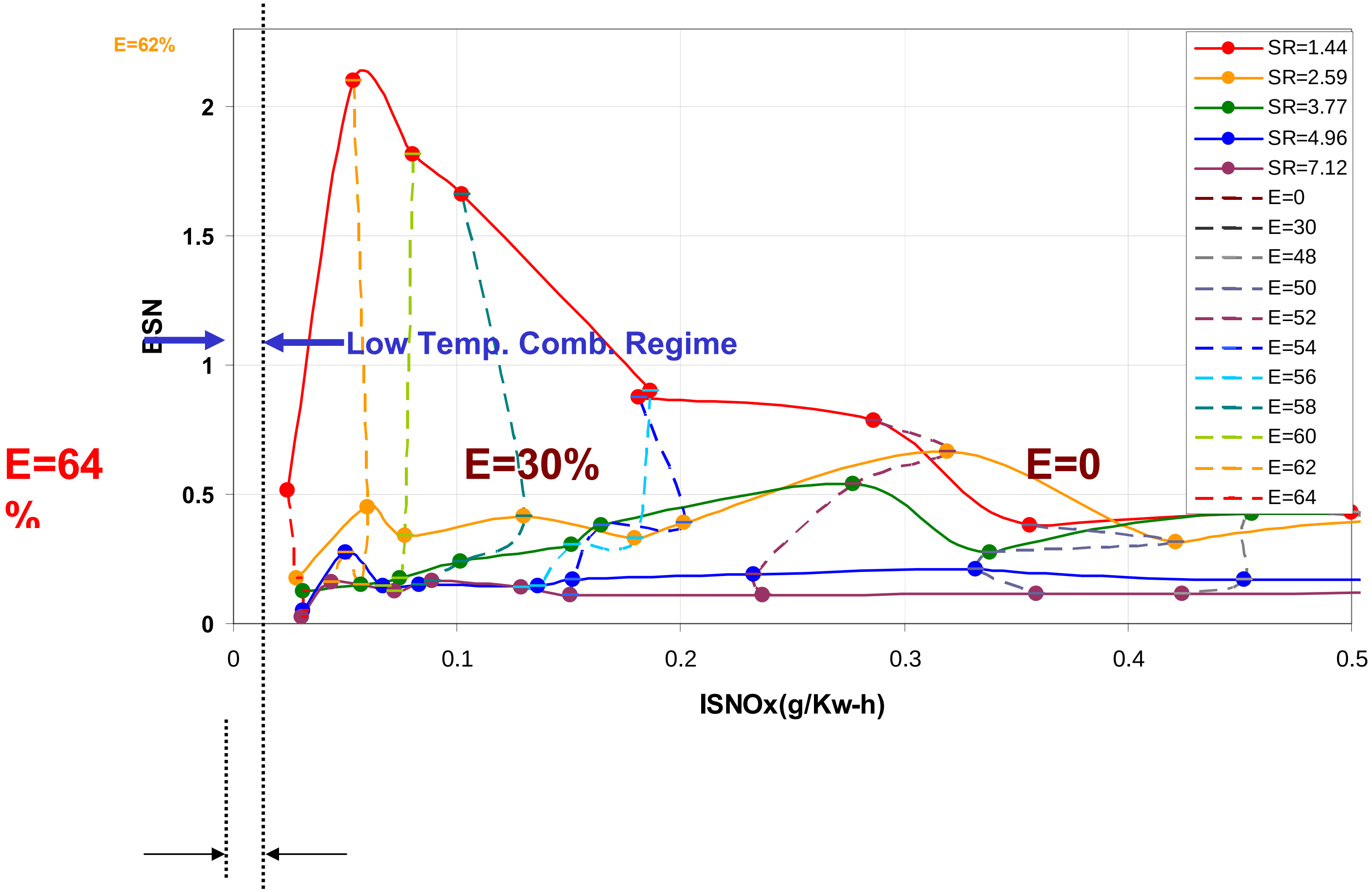
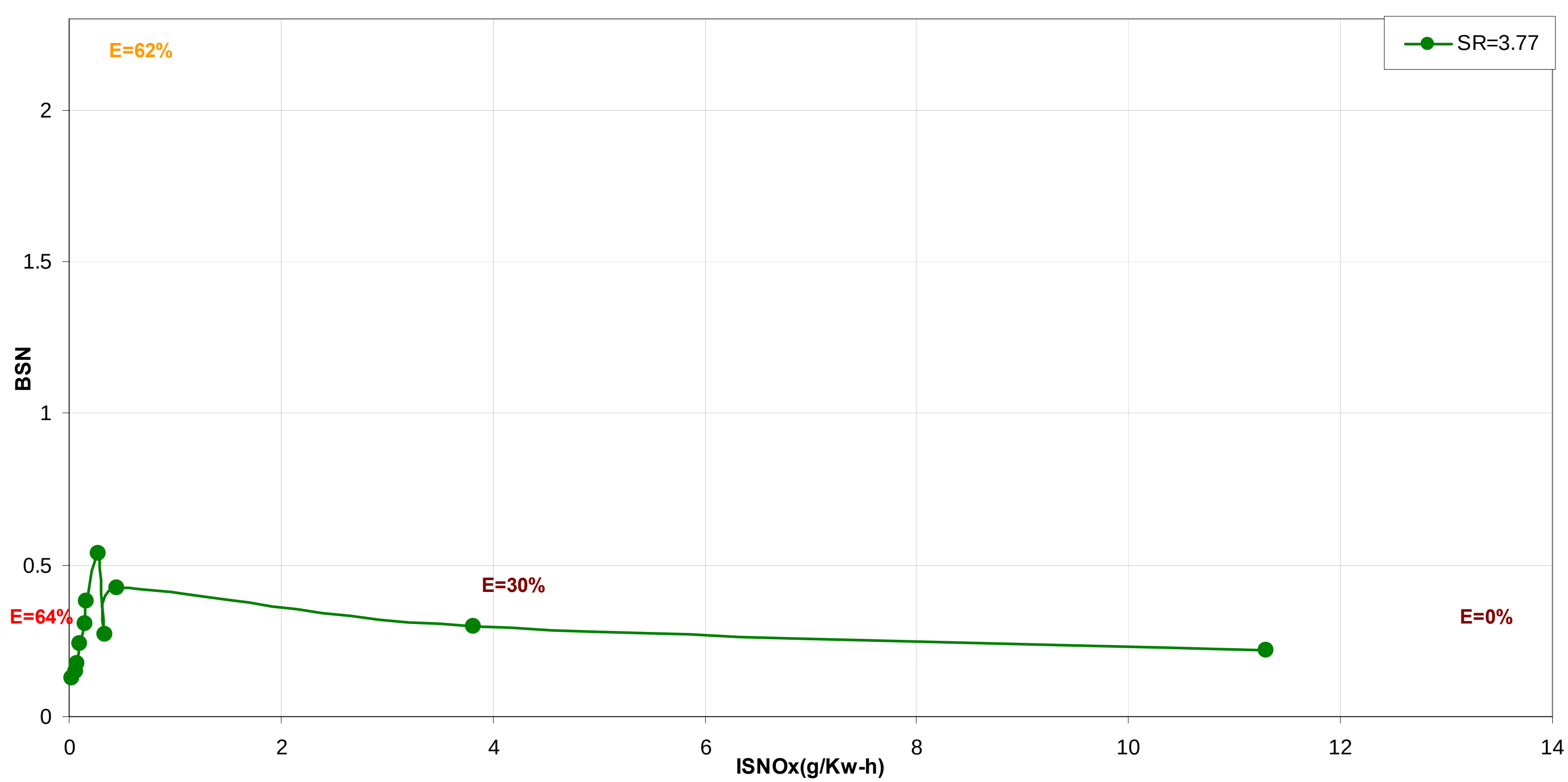
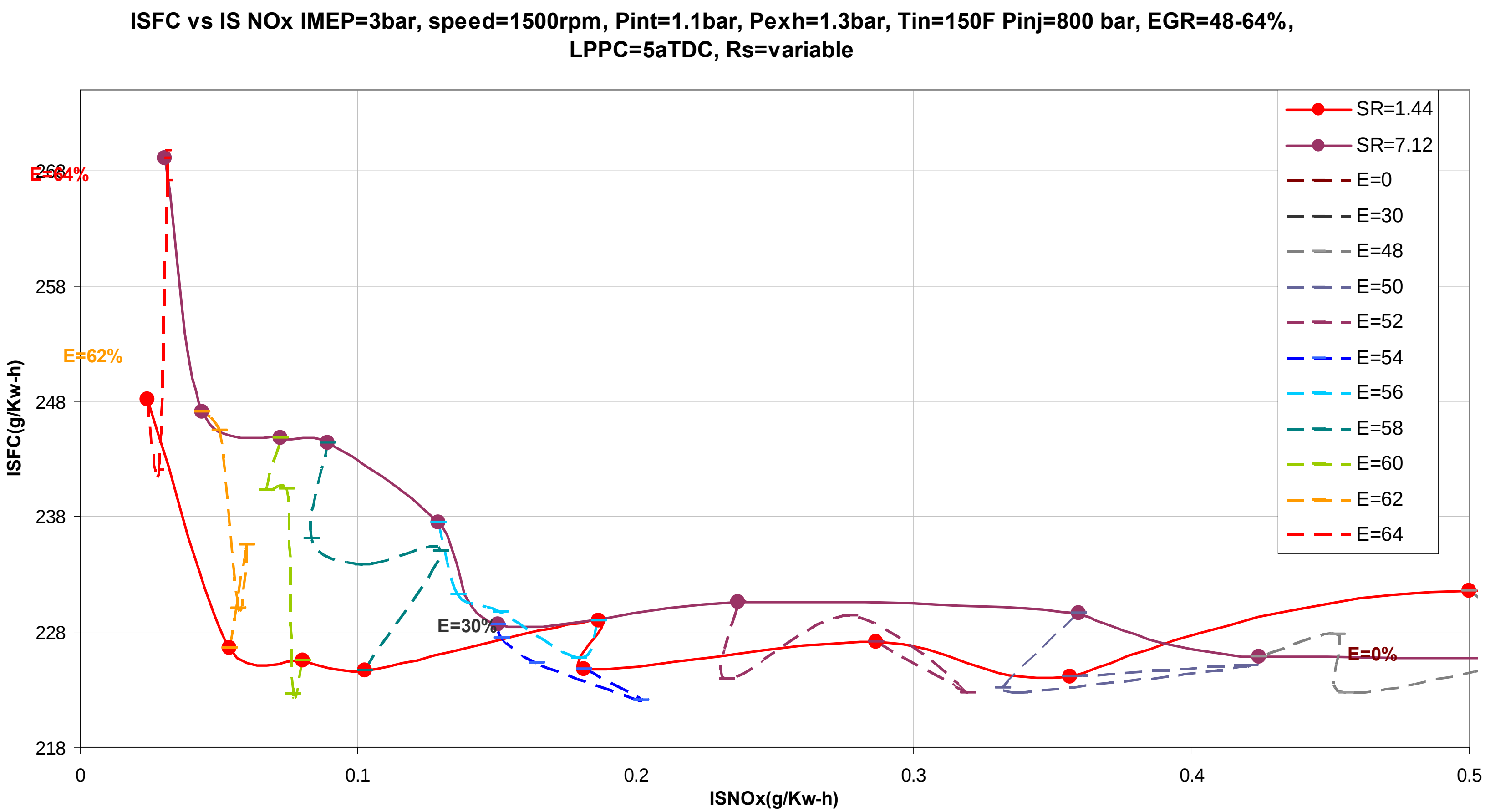
01/28/2003 NAH-WSU

BSN vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable

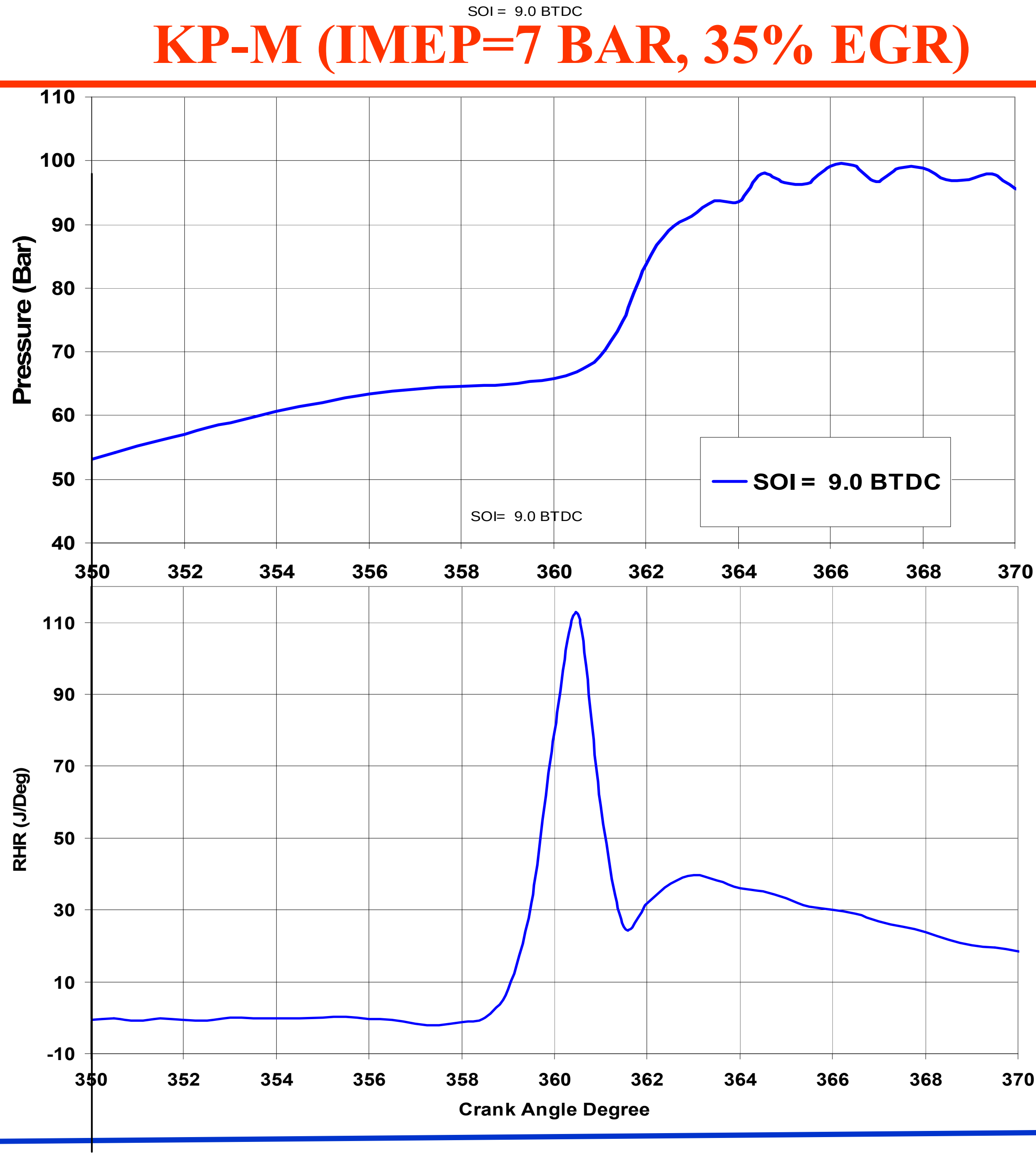


BSN vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable




ISFC vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable
ISFC(g/Kw-h)
ISNOx(g/Kw-h)
E=64%
E=62%
E=30%
E=0%
SR=1.44
SR=7.12
E=0
E=30
E=48
E=50
E=52
E=54
E=56
E=58
E=60
E=62
E=64

PRESSURE TRACES AT DIFFERENT INJECTION TIMINGS, KP-M (IMEP=7 BAR, 35% EGR)



OPERATORS

SWIRL

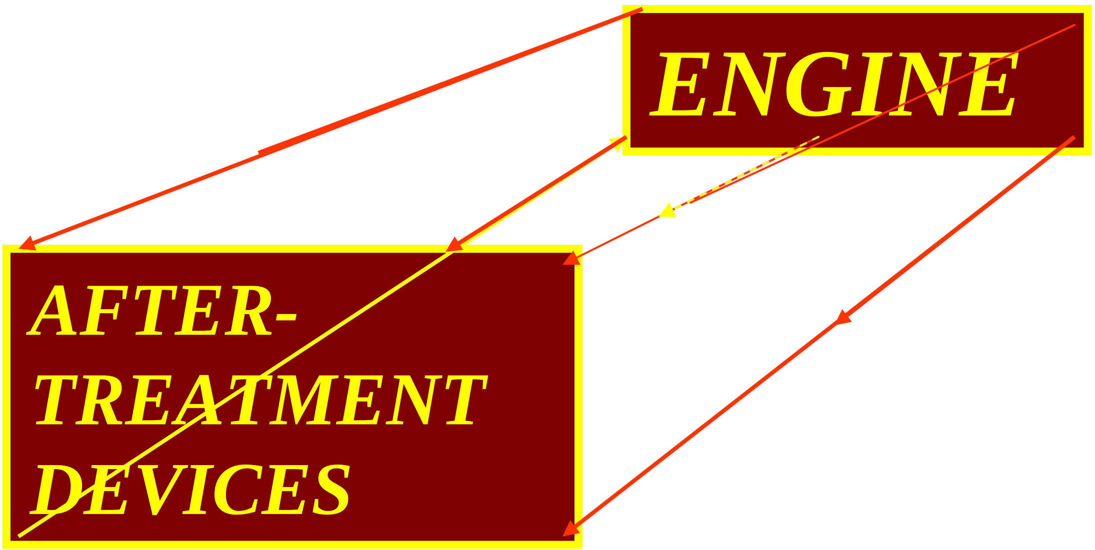
ADVANCE

RETARD

EGR

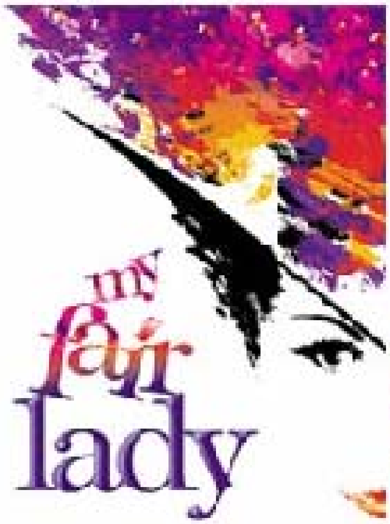
PRESSURE

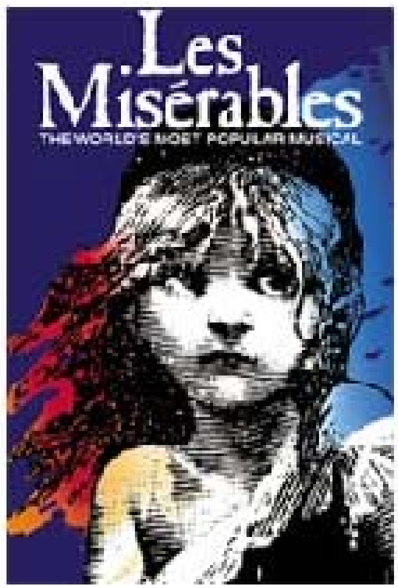
OPTIMIZE

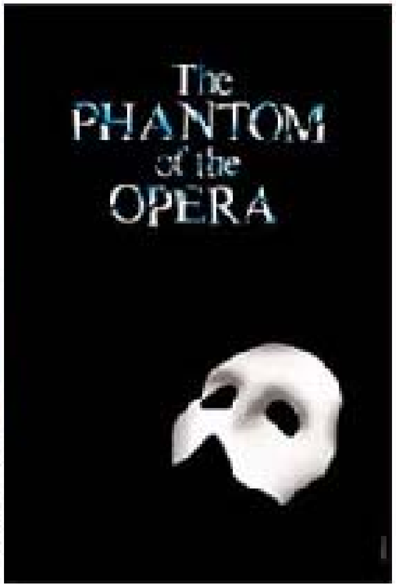


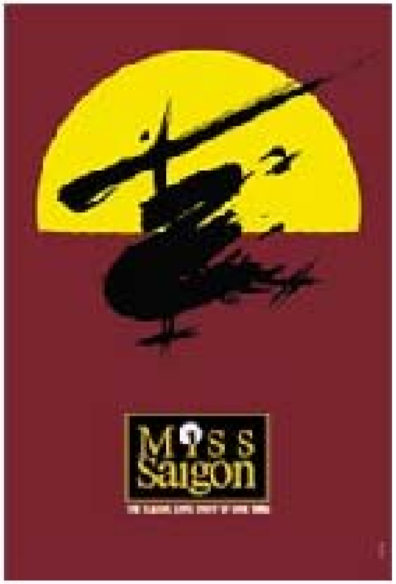
EACH AFTER-TREATMENT DEVICE HAS ITS FAVORATE OPERAS

OPERAS

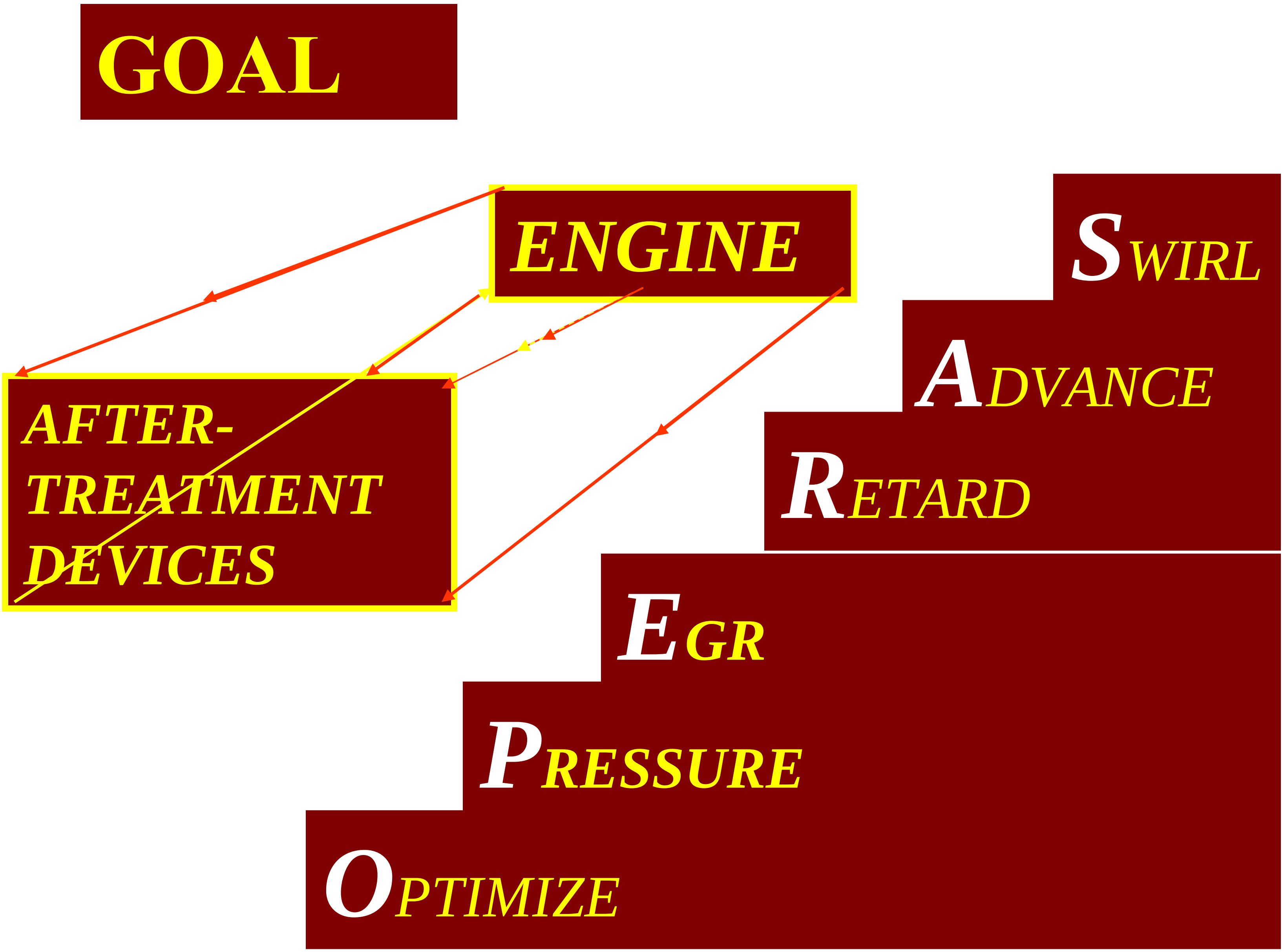








EACH PERSON HAS HER/HIS FAVORATE OPERAS


GOAL
ENGINE
AFTER-
TREATMENT
DEVICES
SWIRL
ADVANCE
RETARD
EGR
PRESSURE
OPTIMIZE

ENGINE OPERAS [SAMPLES]

B. With EGR:

2. **(a) CDPF for the oxidation of soot by O_2**

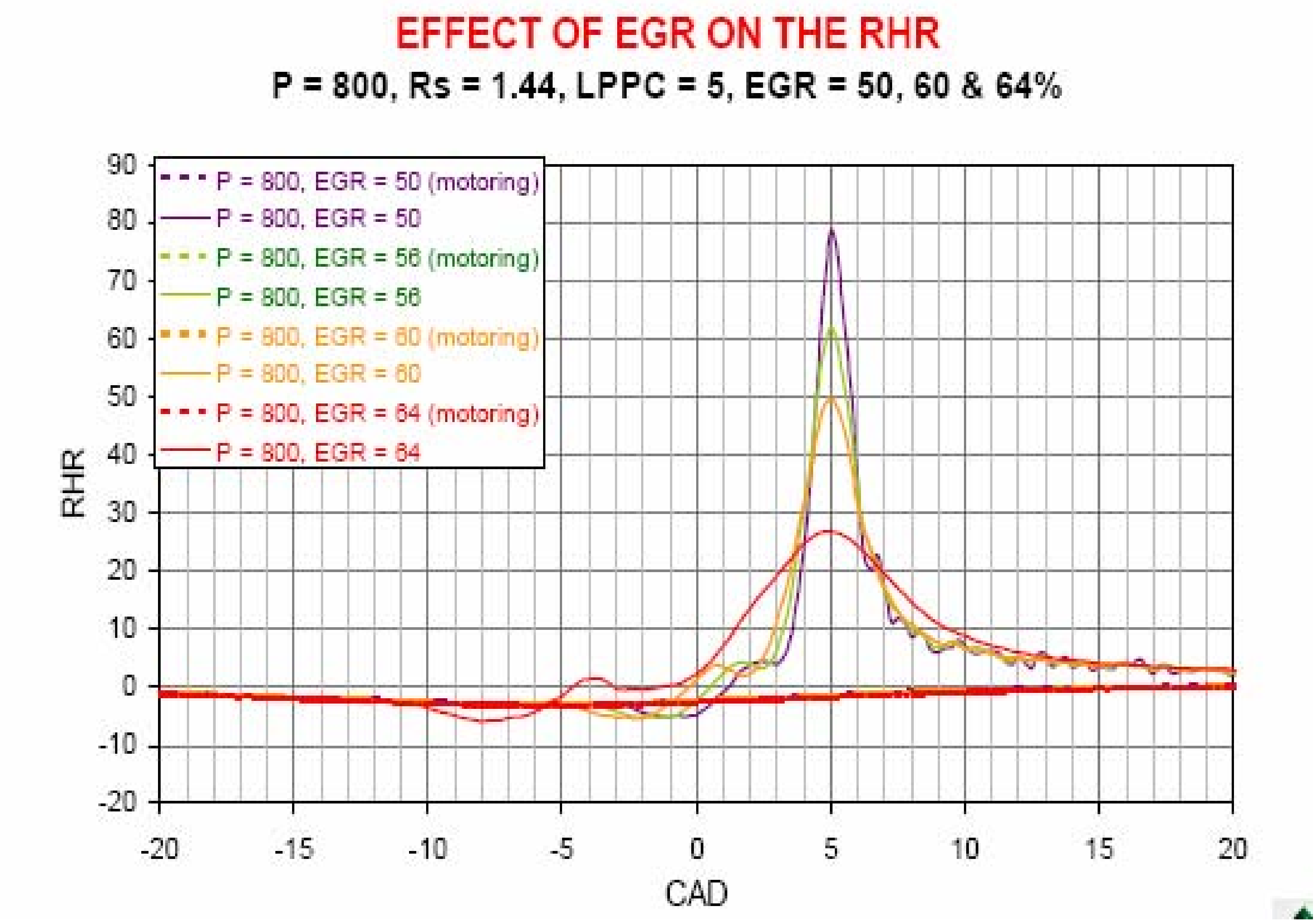
Very high EGR and high injection pressures

(b) CRT for the oxidation of Soot by NO_2

Combinations of injection pressures and %EGR to give the proper ratio **[NO_x/ C]**

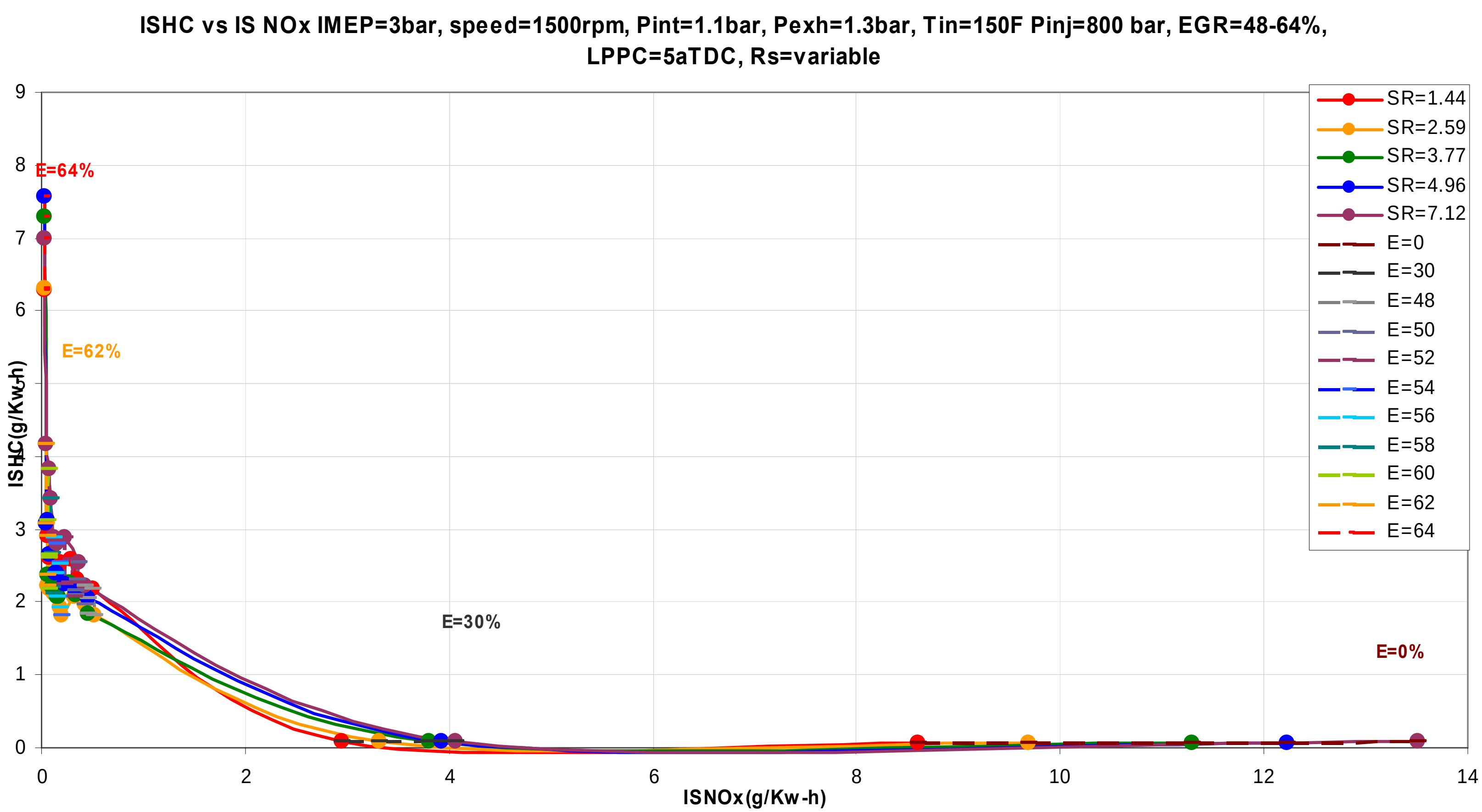
(c) SCR-HC for NO

Combinations of injection pressures and % EGR to give the proper **[HC/ NO]**



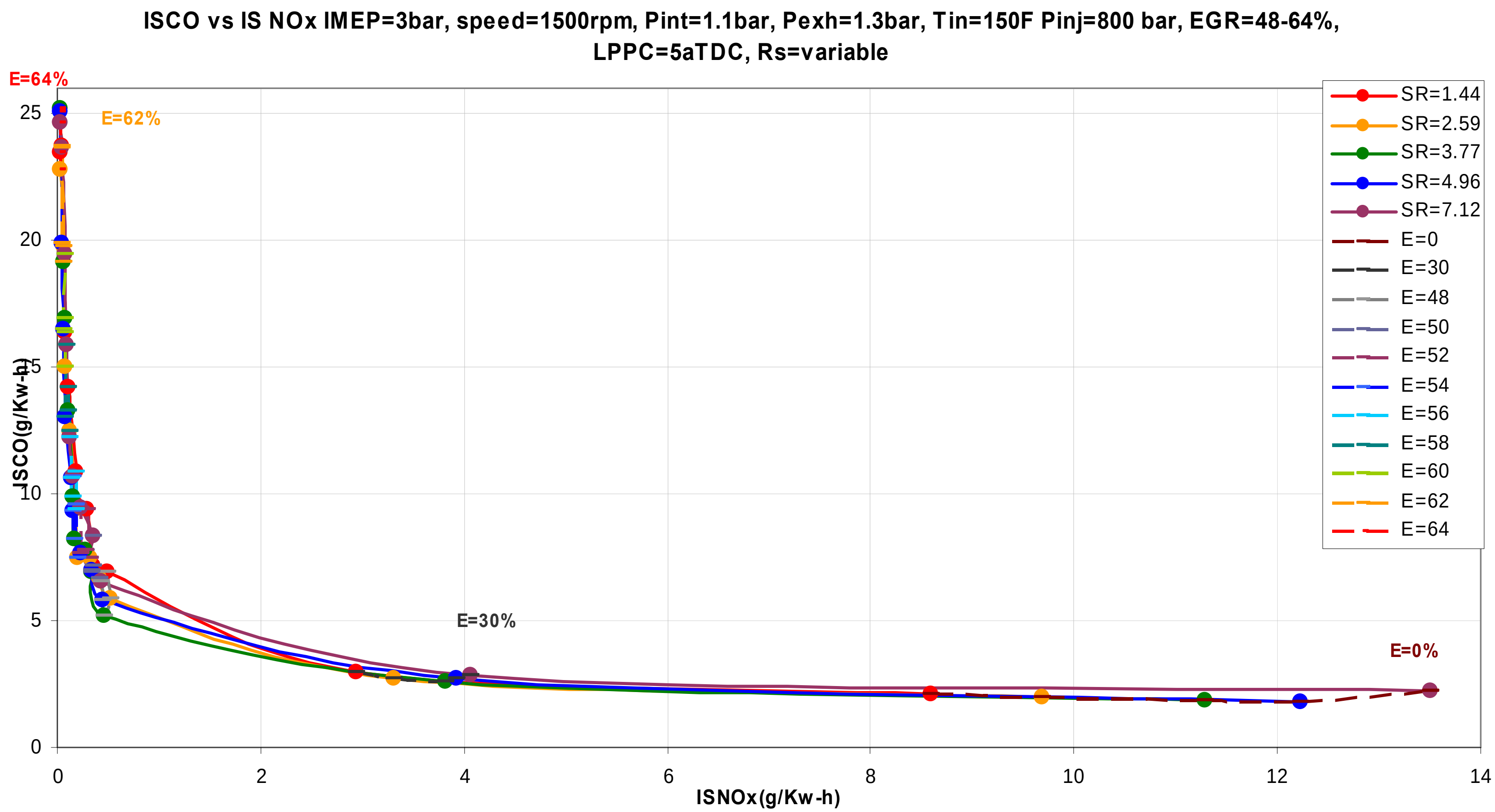
EFFECT OF EGR ON THE RHR
P = 800, Rs = 1.44, LPPC = 5, EGR = 50, 60 & 64%
P = 800, EGR = 50 (motoring)
P = 800, EGR = 50
P = 800, EGR = 56 (motoring)
P = 800, EGR = 56
P = 800, EGR = 60 (motoring)
P = 800, EGR = 60
P = 800, EGR = 64 (motoring)
P = 800, EGR = 64
RHR
CAD
90
80
70
60
50
40
30
20
10
0
-10
-20
-20
-15
-10
-5
0
5
10
15
20

ISHC

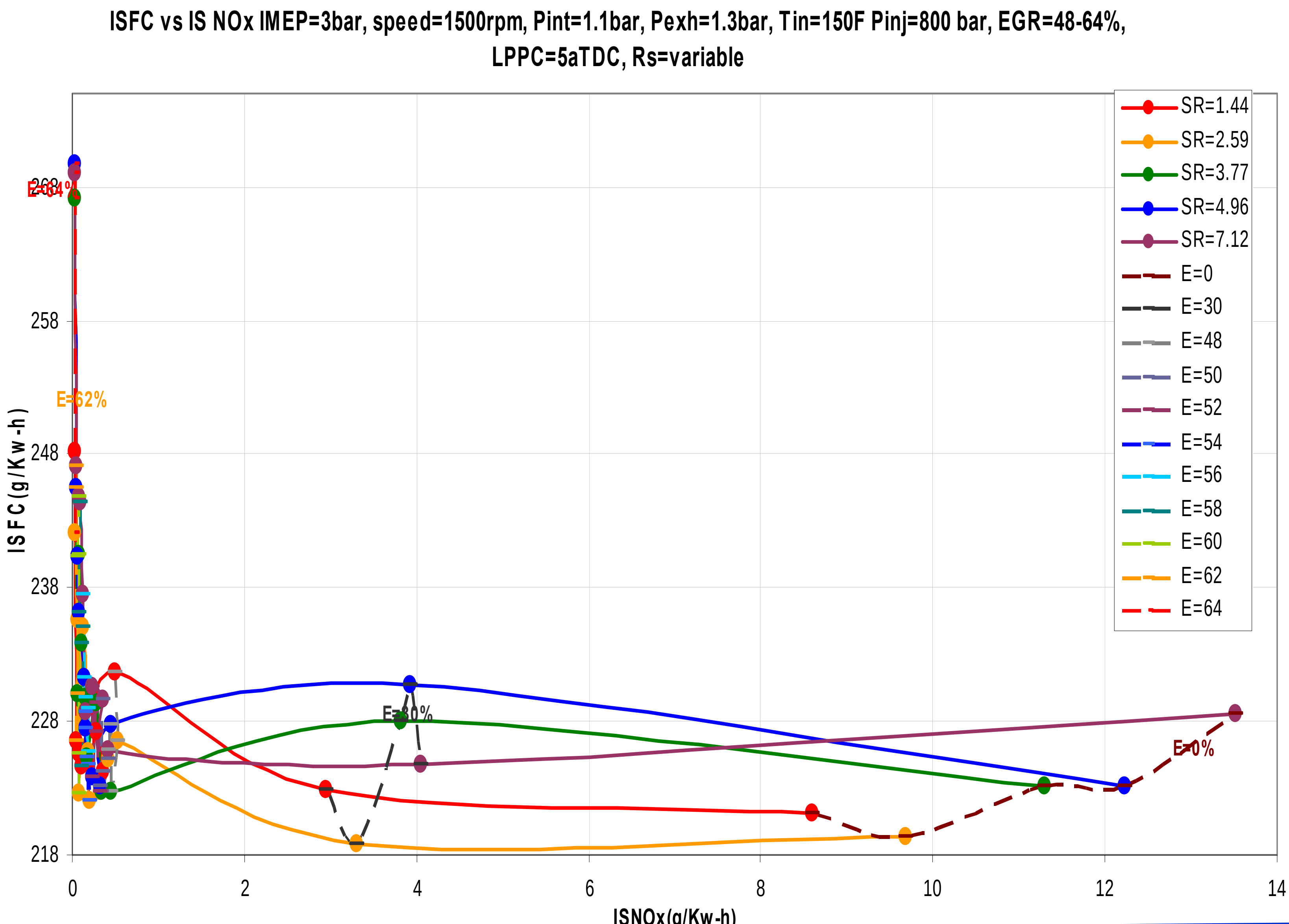


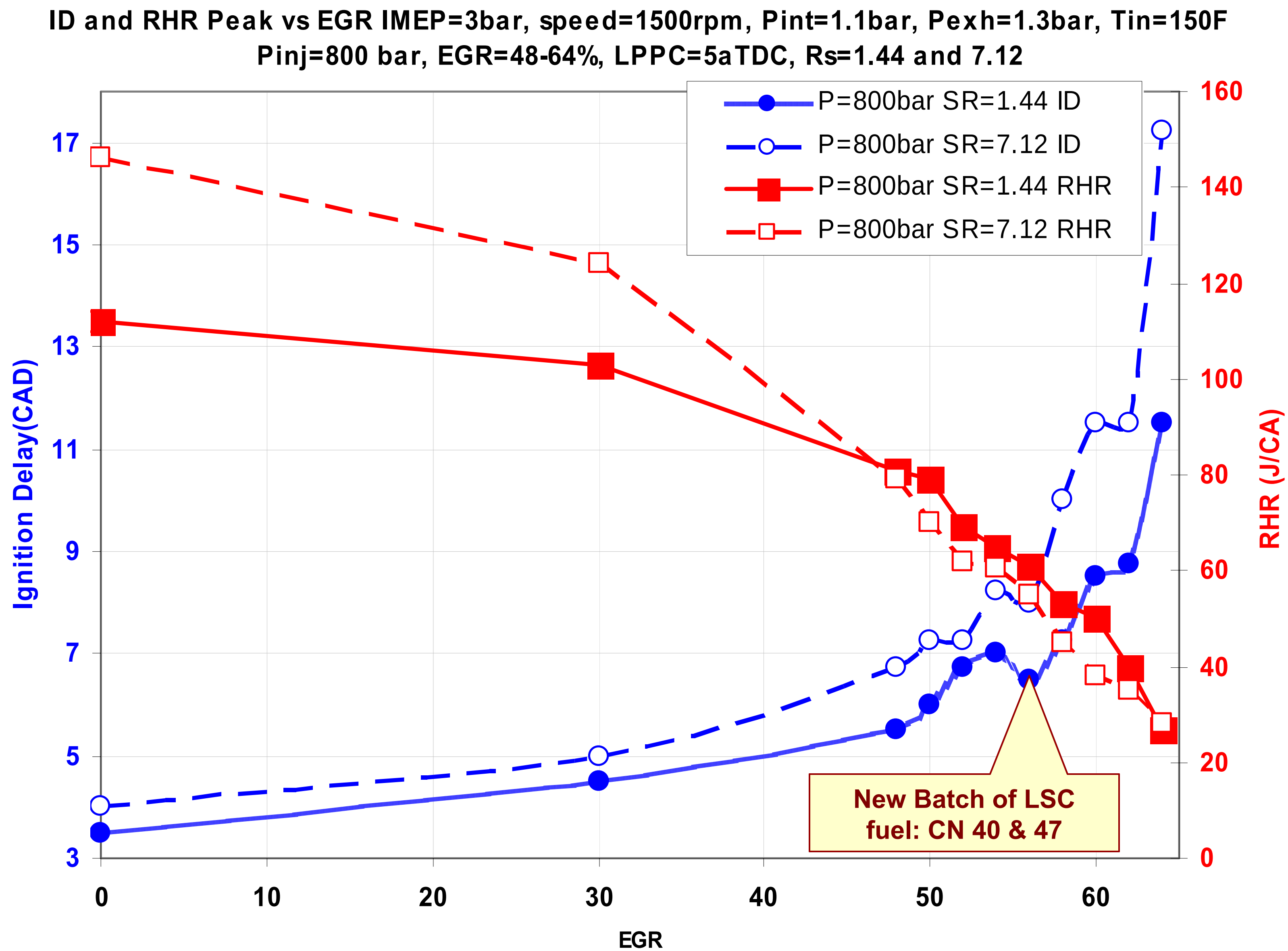
ISHC vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable
ISHC(g/Kw-h)
ISNOx(g/Kw-h)
E=64%
E=62%
E=30%
E=0%
SR=1.44
SR=2.59
SR=3.77
SR=4.96
SR=7.12
E=0
E=30
E=48
E=50
E=52
E=54
E=56
E=58
E=60
E=62
E=64

ISCO

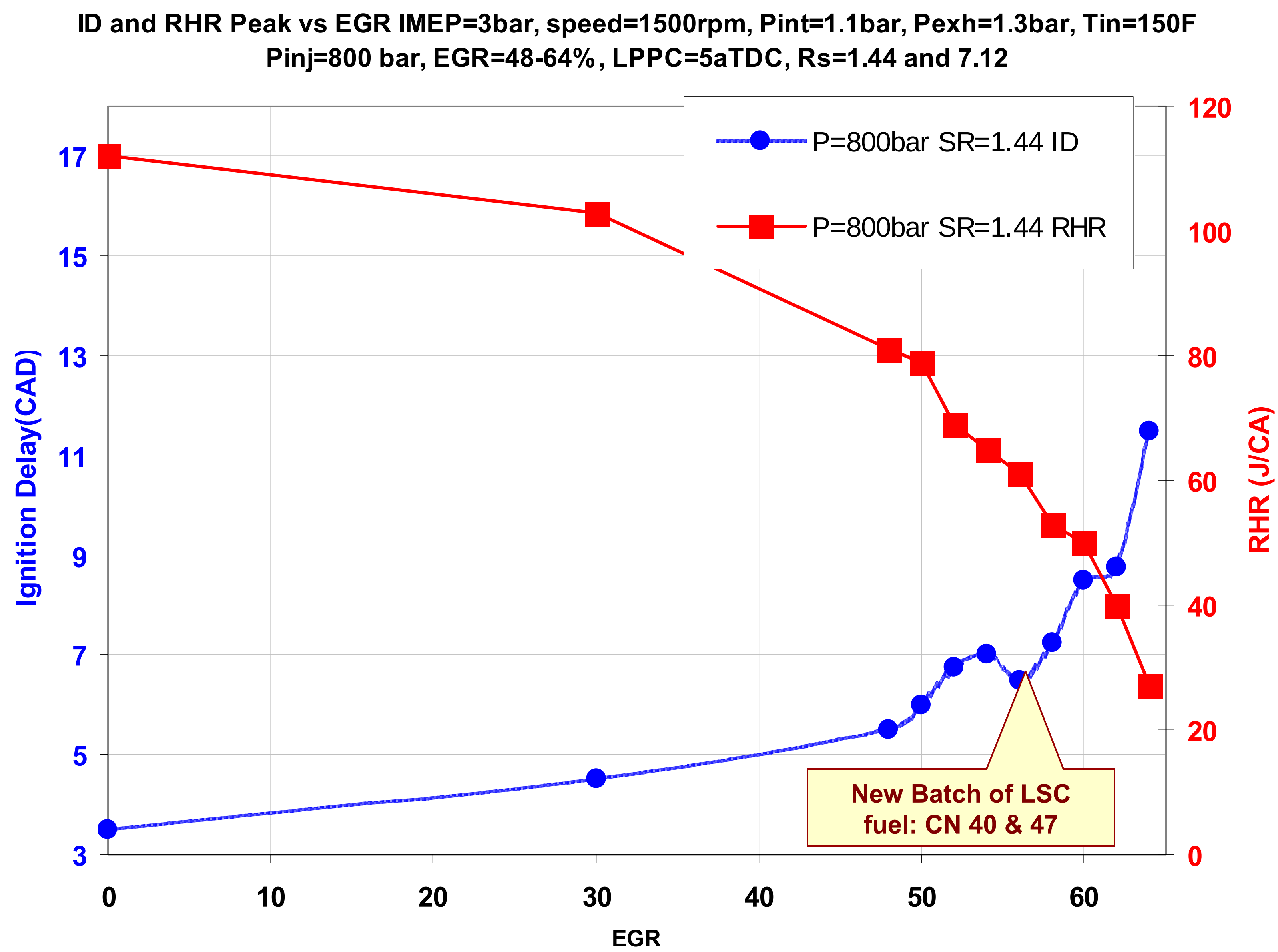


ISCO vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable
E=64%
E=62%
E=30%
E=0%
ISCO(g/Kw-h)
ISNOx(g/Kw-h)
0
5
10
15
20
25
0
2
4
6
8
10
12
14
SR=1.44
SR=2.59
SR=3.77
SR=4.96
SR=7.12
E=0
E=30
E=48
E=50
E=52
E=54
E=56
E=58
E=60
E=62
E=64


ISFC vs IS NOx IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=variable
ISFC (g/Kw-h)
ISNOx(g/Kw-h)
218
228
238
248
258
268
0
2
4
6
8
10
12
14
E=64%
E=62%
E=30%
E=0%
SR=1.44
SR=2.59
SR=3.77
SR=4.96
SR=7.12
E=0
E=30
E=48
E=50
E=52
E=54
E=56
E=58
E=60
E=62
E=64



ID and RHR Peak vs EGR IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F
Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=1.44 and 7.12
P=800bar SR=1.44 ID
P=800bar SR=7.12 ID
P=800bar SR=1.44 RHR
P=800bar SR=7.12 RHR
Ignition Delay(CAD)
RHR (J/CA)
EGR
3
5
7
9
11
13
15
17
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
New Batch of LSC fuel: CN 40 & 47


ID and RHR Peak vs EGR IMEP=3bar, speed=1500rpm, Pint=1.1bar, Pexh=1.3bar, Tin=150F
Pinj=800 bar, EGR=48-64%, LPPC=5aTDC, Rs=1.44 and 7.12
P=800bar SR=1.44 ID
P=800bar SR=1.44 RHR
Ignition Delay(CAD)
RHR (J/CA)
EGR
17
15
13
11
9
7
5
3
120
100
80
60
40
20
0
0
10
20
30
40
50
60
New Batch of LSC
fuel: CN 40 & 47

LTC-OT

Concept

To avoid the penalty in fuel economy and combustion instability:

- **Advance injection timing (LPPC:5°bTDC)**
  – Side effect: increase in NOx.
- **Increase EGR**
  –Side Effect: increase in soot
- **Improve mixture homogeneity**
  - Increase injection pressure (**from 800 bar to 1200 bar)**
  - Optimize swirl motion
  - Other approaches

MK CONCEPT

- To reduce **NOx** and **smoke** engine-out emissions, burn a **premixed** fuel vapor- air charge, **low in oxygen** concentration, **at low temperatures**
- To reduce oxygen concentration, use high EGR ratios.
- In addition, EGR would reduce the combustion products temperature and NO formation.
- EGR would also reduce the rates of the autoigniton reactions, increase the ignition delay period, and allow more time for mixing before the start of combustion. This reduces soot emissions.

BACKGROUND

- The presentation today is based on data obtained in a program entitled "Characterization of Single-Cylinder Small-Bore, 4-Stroke CIDI Engine Combustion".
- This program is sponsored by DOE Office of FreedomCar and Vehicle Technologies under the leadership of Gurpreet Singh, and the technical direction of Dennis Siebers, Manager Engine Combustion, Sandia National Lab.
- Other support comes from U.S. Army TARDEC, NAC and ARC.
- In this presentation we will look at the engine as a part of a system composed of the engine and the after treatment devices.
- Different types of after treatment devices might be needed for the diesel engine to meet the strict future emission standards, particularly for NOx and PM.
- The efficiency of any after-treatment device depends on the properties of the feed gas, mainly its composition, temperature, …
- The properties of the feed gas are the result of the in-cylinder combustion process
- New diesel combustion regimes have been developed during the last five years.

TRADE-OFF Between NOx and HC, 600 bar
Injection timing effect (KP2 , 320 MINISAC)