The Effects of Inflation Gas on Tire Laboratory Test Performance

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National Highway Traffic Safety Administration

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- **NHTSA Traffic Safety Facts, 2006***
  - In 2006, there were an estimated 5,973,000 police-reported traffic crashes, in which:
    - 42,642 people were killed
    - 2,575,000 people were injured
    - 4,189,000 crashes involved property damage only
  - Motor vehicle crashes are the leading cause of death for every age from ages 2 through 34
  - From 1994 to 2004, NHTSA estimates that about 400 fatalities, annually (~1% of total motor vehicle fatalities), may be attributed to tire failures of all types

**NHTSA Traffic Safety Facts, 2006 Data, DOT HS 810 809, NHTSA's National Center for Statistics and Analysis, Updated March 2008*

Nitrogen Inflation of Pneumatic Tires

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- **Inflation of tires with N_2 gas is presumed to be beneficial. However, there are a wide variety of claims and counter-claims:**
  - Better inflation pressure retention
  - Lower rolling resistance
  - Better treadwear
  - Lower running temperatures
  - Better tire durability
  - Less moisture
  - Etc.

NHTSA Testing of Tires with Nitrogen Inflation

- **NHTSA re-directed tires from other tire programs to address four basic questions:**
  - Is there a systematic and quantifiable difference in the inflation pressure loss rate (IPLR) of tires when inflated with gases of varying nitrogen to oxygen ratios?
  - Are the observed differences in IPLR uniform among tires, or are they related to variables such as initial inflation pressure, or tire design and composition?
  - Are there direct effects of inflation gas composition on the rolling resistance of tires?
  - Are there differences in tire durability performance after accelerated aging with different nitrogen-to-oxygen ratios?

Testing

- **In total, twenty-five different passenger or light truck tire models were inflated with:**
  - Shop air with air line dryer
  - Dry N_2 gas from 94 to 99% purity
    - Initial purge and refill used
  - Gas composition measured at the beginning and end of test
- **Tires were tested for:**
  - Inflation pressure loss rate
  - Laboratory rolling resistance
  - Roadwheel endurance after oven aging

Tire Inflation Pressure Loss

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- **Under-inflated tires are a significant problem**
  - According to a NHTSA study, 27% of passenger cars and 32% of light trucks have at least one tire that is substantially underinflated*
    - "Operating a vehicle with substantially under-inflated tires can result in a premature tire failure, such as instances of tread separation and blowouts, with the potential for a loss of control of the vehicle. Under-inflated tires also shorten tire life and increase fuel consumption." **

**Tire Pressure Special Study @ http://www.nhtsa.dot.gov/people/ncsa/*

***U.S. Transportation Secretary Norman Y. Mineta @ http://www.dot.gov/affairs/nhtsa4601.htm*

Tire Inflation Pressure Loss

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- **Tires lose inflation gases continuously, since rubber compounds are permeable to gas molecules (losses also exist through tire/wheel/valve interfaces)**
- **Tubeless tires require an innerliner compound with low permeability to limit the loss of inflation**
- **The ASTM F1112-06 test measures the static loss of inflation gas from a tire over time**
  - Data is reported as % loss / month

ASTM F1112-06 Inflation Pressure Loss Rate (IPLR)

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- **Test Room**
  - Mean temperatures of 21, 24, 30 or 38°C (normal test is 21°C) ±0.6°C (±1°F)
  - Forcibly circulated air controlled at ±3°C (±5°F)
- **Gauges or Pressure Transducers**
  - Resolution 2 kPa (0.25 psi) accurate to ±1% of measured value (operating within 40 to 90% of full scale)
- **Data Acquisition**
  - Record data once per day for 180 days; or computer data acquisition of more data points per day for a shorter duration test
- **Barometer (High Accuracy)**

ASTM F1112-06 Inflation Pressure Loss Rate (IPLR)

- **Tires are inflated to a specified pressure and sit static and unloaded in a controlled environment**
  - NHTSA testing used FMVSS No. 139 High Speed test pressures
  - NHTSA testing was conducted at 21ºC ± 3ºC
- **The pressure and conditions are monitored over time**
  - NHTSA testing used 90 days with continuous monitoring of the pressure via computer interface
    - Per the ASTM standard the first 30 days data was discarded
- **Data is then corrected to a standard temperature and barometric pressure**
  - 21ºC and 101.3 kPa

Example Data Output

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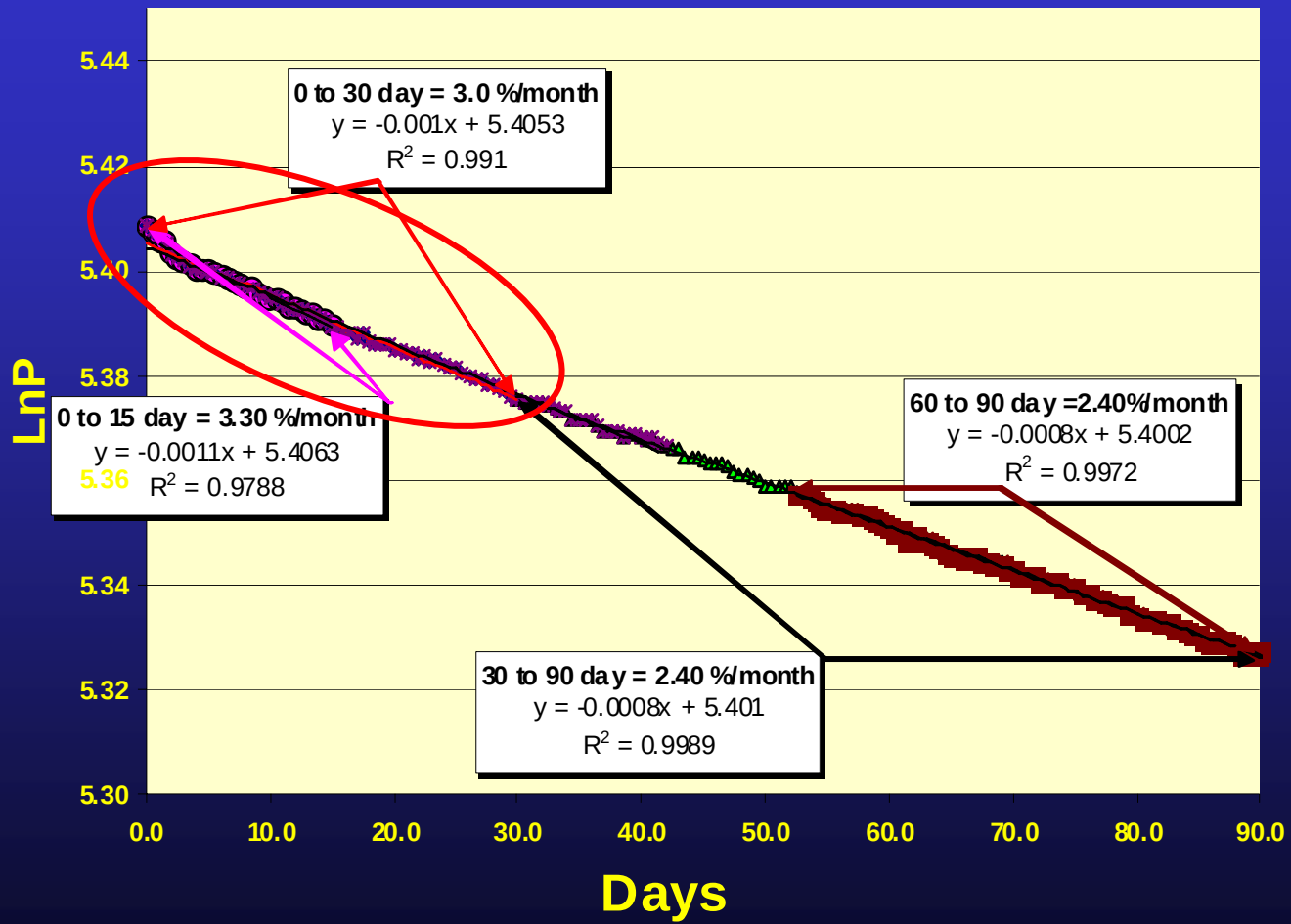
Rate stabilizes during initial 30 days



30 - 90 day data is used to calculate Inflation Pressure Loss Rate (IPLR)

Is there a difference in (IPLR) when varying N_2/O_2 ratio?

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- **One-way ANOVA analysis of IPLR:**

Dependent Variable: IPLR, Rate @ 90 Days, %/month

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	R-Square
Model	27	56.41	2.089	**22.56**	**<.0001**	**0.902**
Error	66	6.11	0.092			
Corrected Total	93	62.52				

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Inflation Gas	1	6.842	6.842	**73.90**	**<.0001**
Test Lab	1	0.017	0.017	0.19	0.6668
Tire Type	25	40.53	1.621	**17.51**	**<.0001**

Inflation Gas and Tire Type are Significant Variables

IPLR with Air vs. N_2 Inflation

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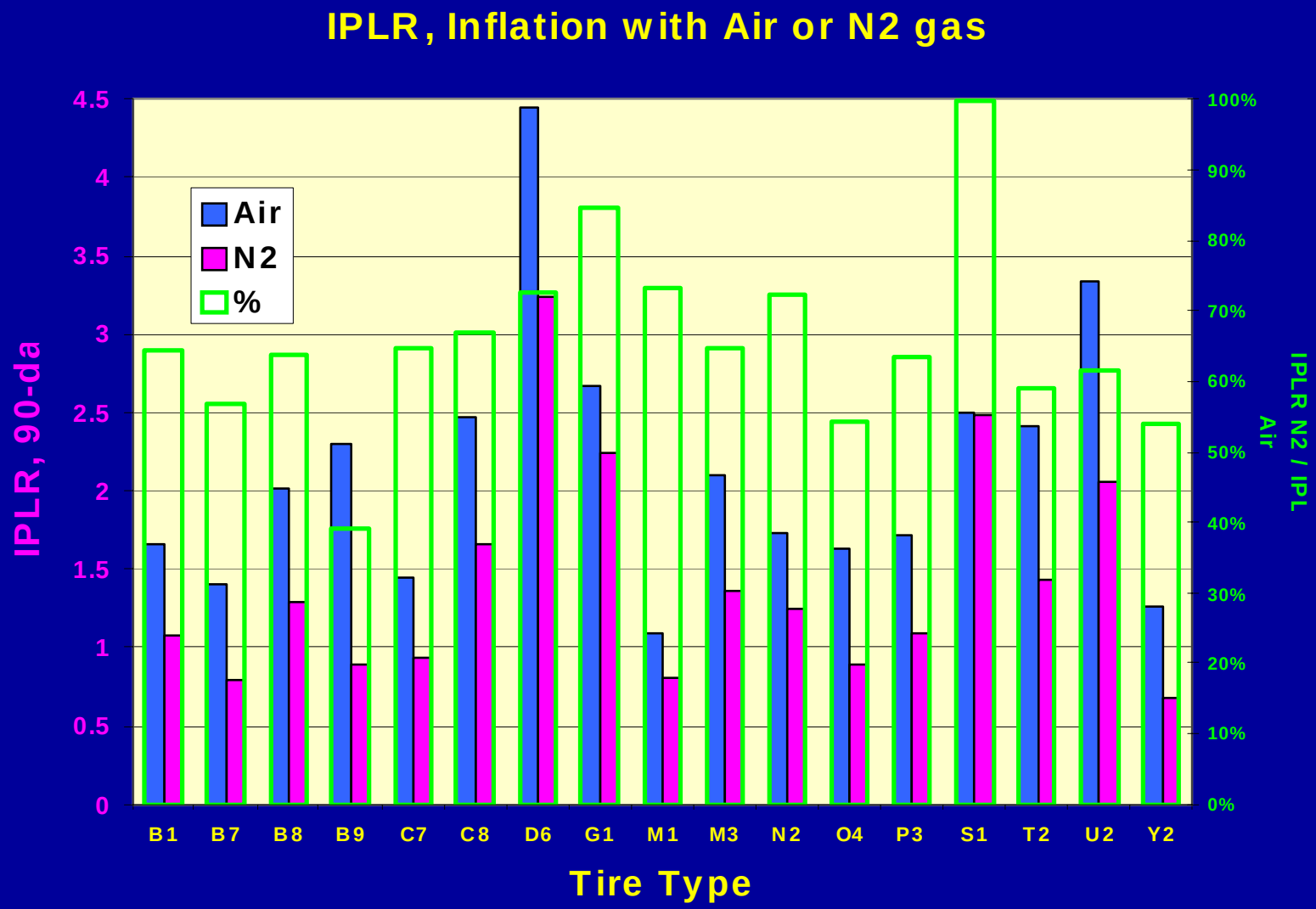
17 Different Models of Tires

Average IPLR for N_2 was 66% of Air



Tire Parameters

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- **Approximate innerliner variations:**
  - Polymer: 100% IIR → 80/20 NR/SBR
  - Carbon black: 53 → 76 phr
  - Non-black filler: 0 → 22 phr
  - Total filler: 67 → 105 phr
  - Volatiles: 13 → 26 phr
  - Thickness 0.67 → 1.85 mm
- **Initial Inflation Pressure: 220 → 521 kPa**

IPLR Versus Tire Construction

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- **Of the variables studied, innerliner composition and minimum innerliner thickness in the crown had most significant effect on IPLR**
  - Filler and volatiles had significant, but lesser effects
- **Analysis of <u>difference in IPLR</u> between air and N_2 ($IPLR_{air} - IPLR_{nitrogen}$) by tire type**
  - No significant effect of any construction parameter
  - No significant effect of initial inflation pressure
    - i.e. no difference for Passenger vs. LT tires

Benefits of Nitrogen Inflation on IPLR Appear to be Applicable to All Tire Types

Oxygen Concentration Measurement Equipment

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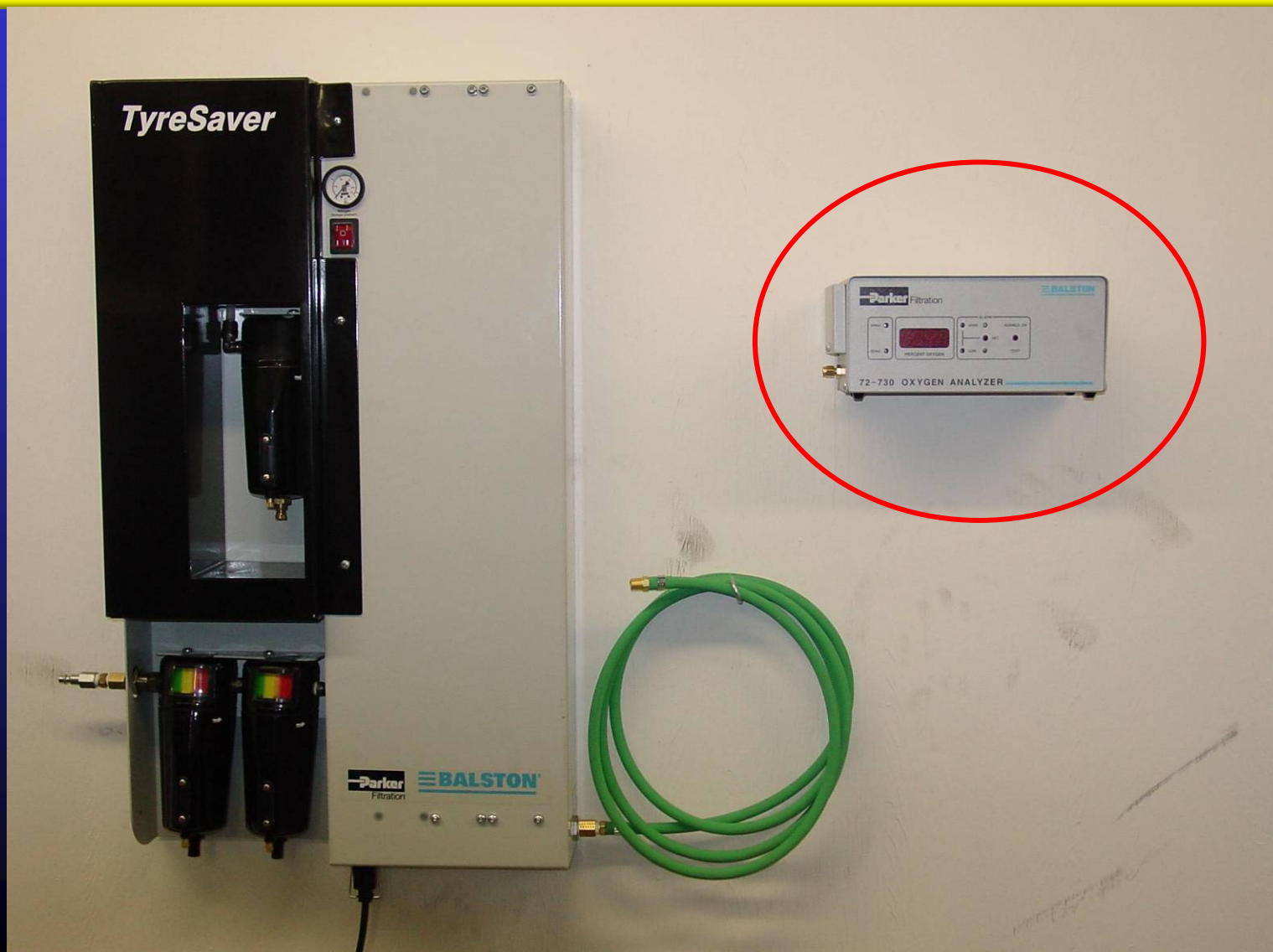
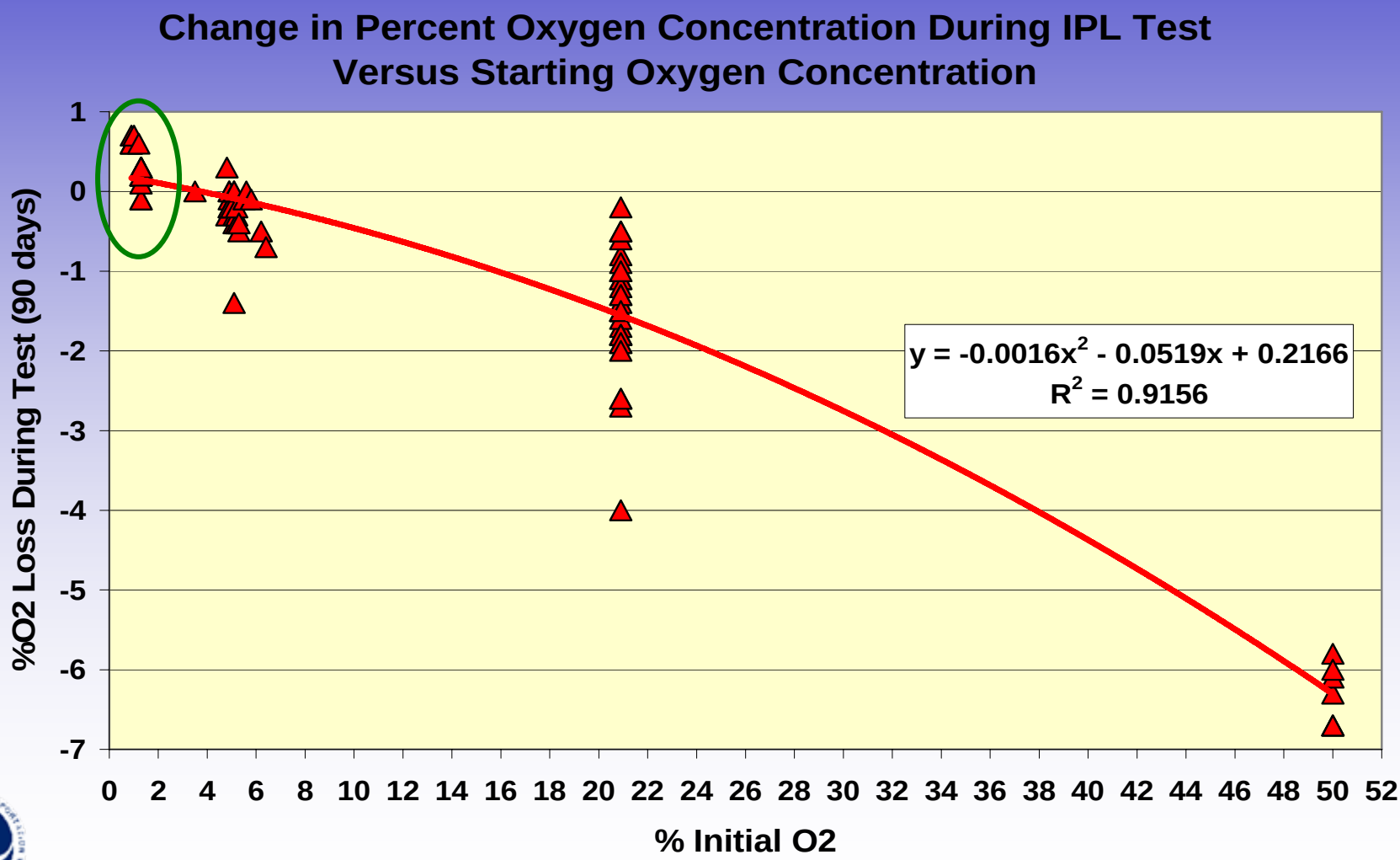
Balston ®
72-730
Oxygen
Analyzer
Accurate to
<0.1% O_2



O_2 Migration During Test



Change in O_2 Levels

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- **Faster migration of O_2 changes mixture of gas during 90-day test**
  - Tires inflated with air lost average of 1.5% O_2
  - Tires inflated with N_2 lost or gained O_2 to approach equilibrium partial pressure
- **Validation of Laboratory Results with On-Vehicle Data**
  - O_2 levels were measured for 76 tires that were in-service (19 vehicles) in Akron, OH
  - Tires were originally inflated with shop air at various locations, no special procedures

No Correlation Between Inflation Pressure and % O_2

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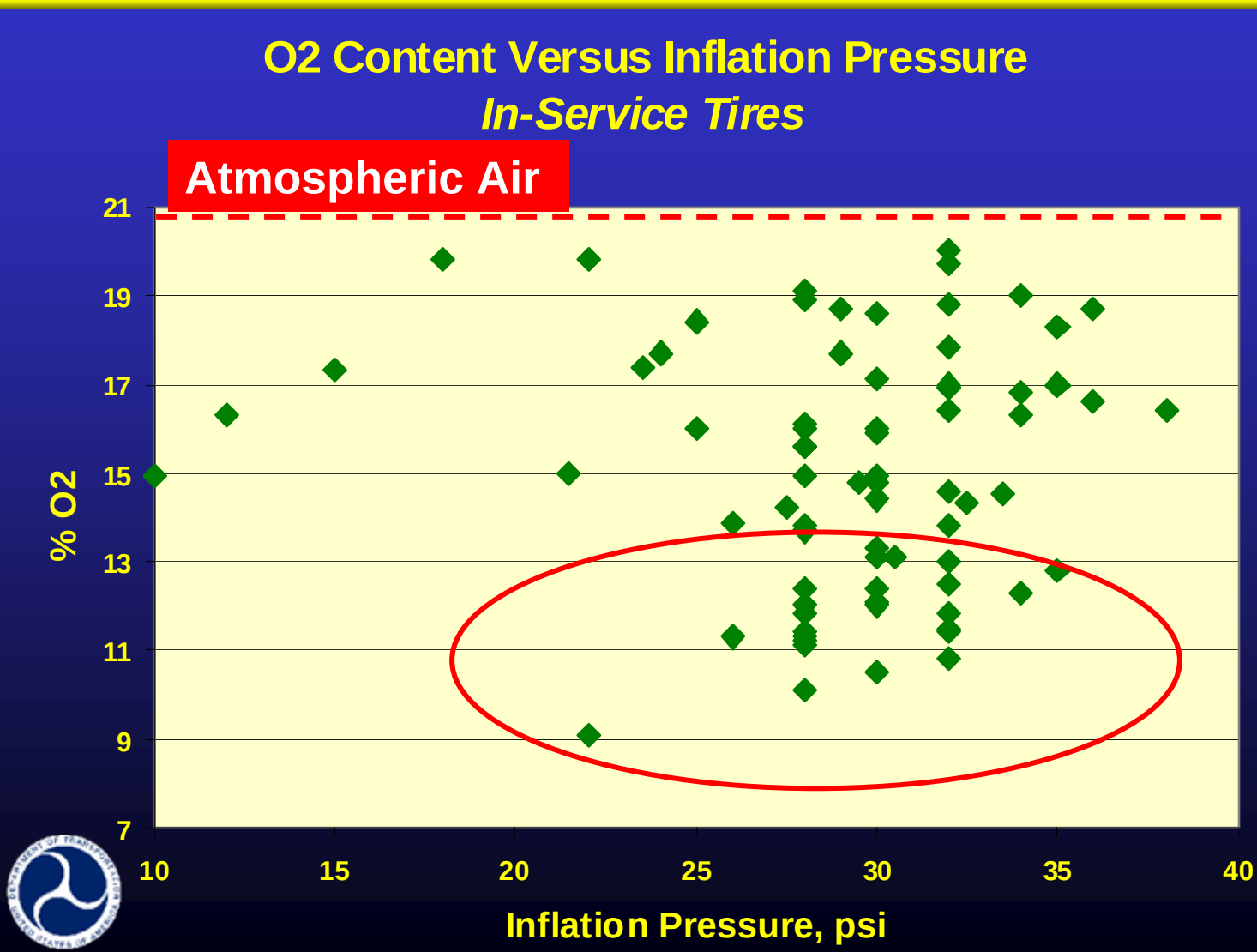

During service with top-offs of normal air, the oxygen permeates out at a faster rate than the nitrogen.

This can result in a >50% reduction in net oxygen levels in the tire inflation gas during normal service.

O_2 Level Significantly Reduced In-Service

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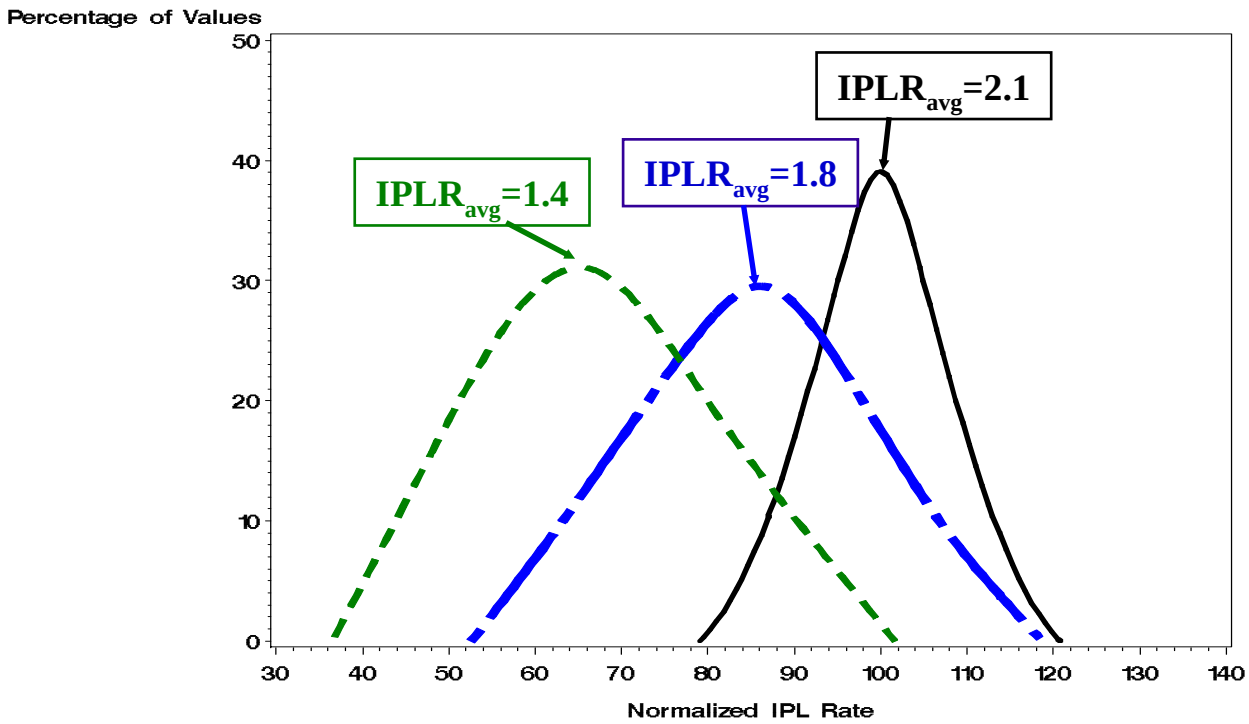
Oxygen Range (% of inflation gas)	Number of Tires
9 → 11	4
11.1 → 13	18
13.1 → 15	18
15.1 → 17	17
17.1 → 19	14
19.1 → 20.0	5
15.02	Average
2.79	Standard Deviation

Indicates Reduced Potential Benefits for N_2 Inflation in Normal Tire Service

IPLR Advantage for N_2 In Service



Theoretical Distribution of IPLR Normalized to Air Rate = 100 for Tire Type. Normalized Distribution of:

_____ Air with 20.9% O2 _____

---------- Nitrogen ----------

__- Air, Depleted of O2 in Service __-

Dynamic Inflation Pressure Loss – Roadwheel Testing

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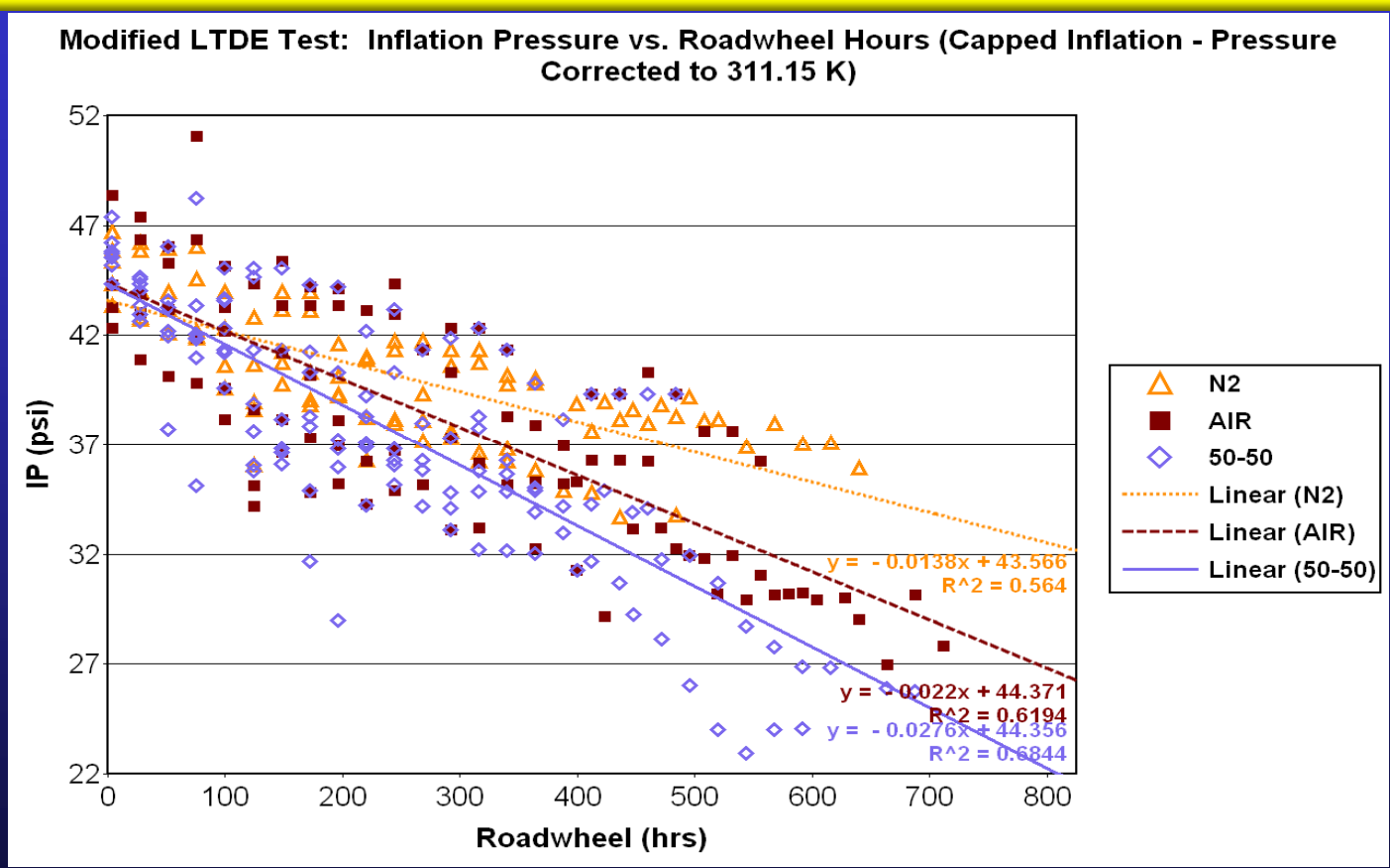

Inflation Pressure Loss During Roadwheel Testing Was 37% Less for Tires Inflated with N_2 vs. Tires Inflated with Air

Change in $\%O_2$ During Dynamic Loaded Operation

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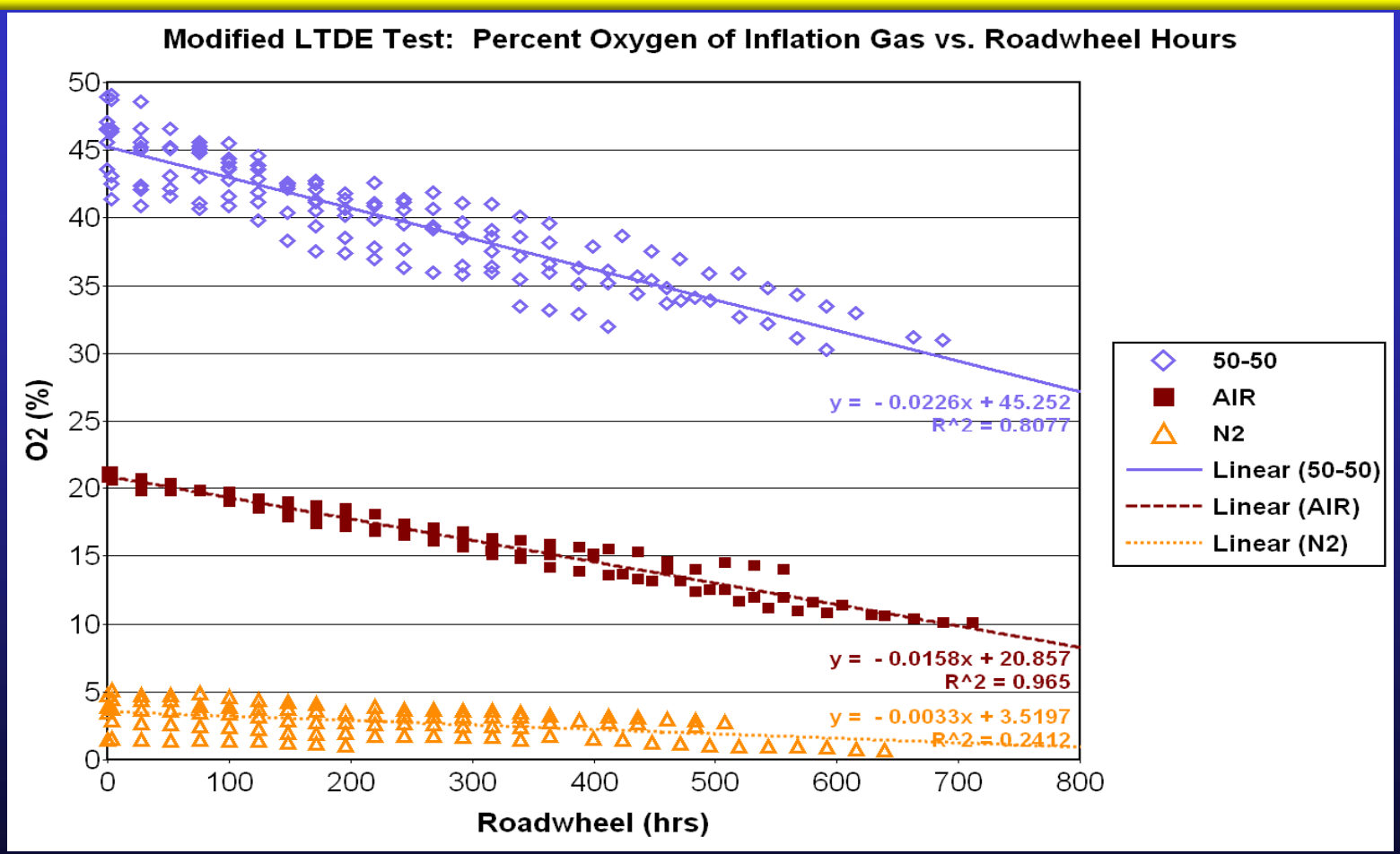

Higher $\%O_2$ Gas Diffuses More Rapidly During Dynamic Roadwheel Testing

Does N_2 Have a Direct Effect on Rolling Resistance?

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- **24 Tires were compared for Rolling Resistance, either inflated with N_2 or Air**
  - SAE J1269 Single-Point Test
- **Average Rolling Resistance**
  - Air = 12.80 pounds ±0.38
  - N_2 = 12.65 pounds ±0.44

- **No Direct Effect Observed for N_2 Inflation on Tire Rolling Resistance**
- **The Only Significant Effect on Tire Rolling Resistance may be Indirect:**
  - Due to Better Retention of Inflation Pressure over Time

Effects on Tire Durability

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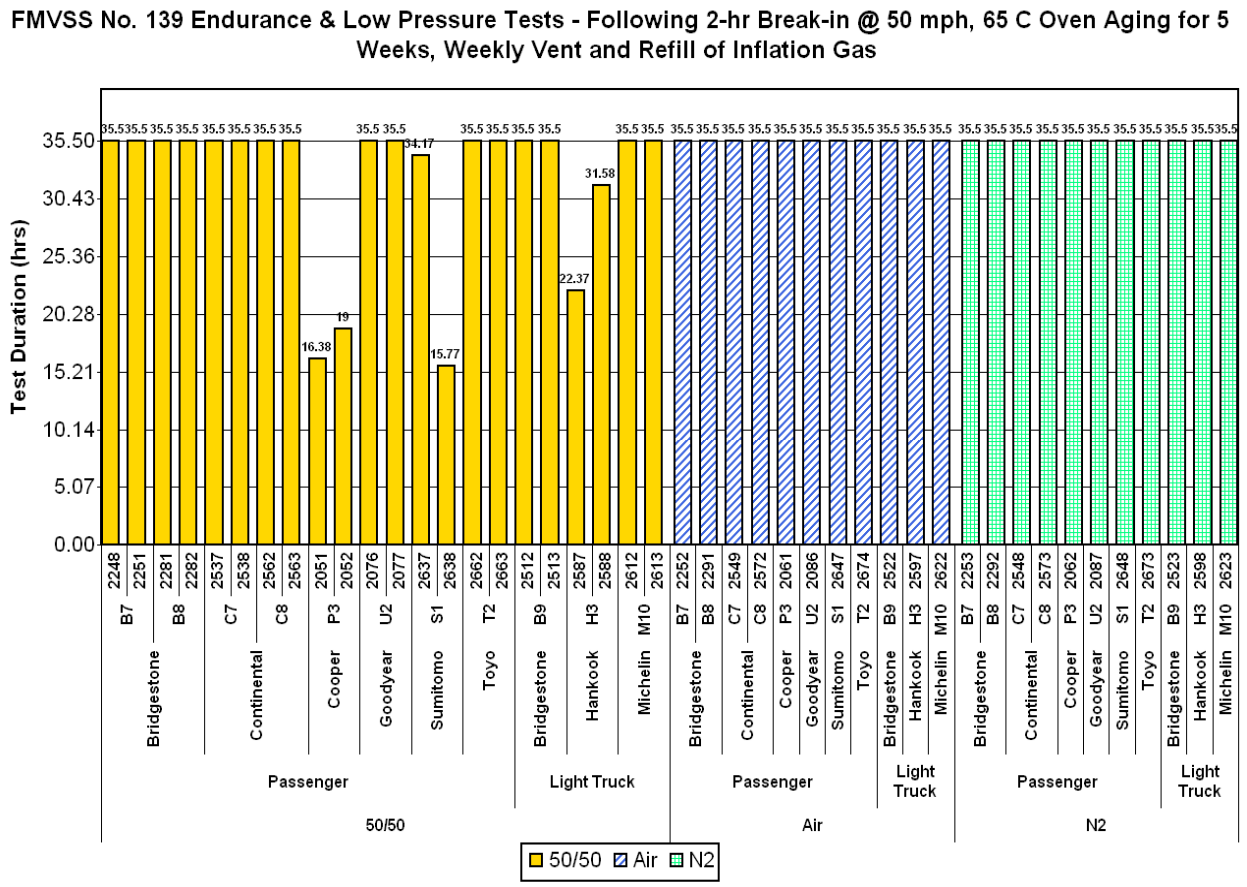

The benefits of N_2 inflation on oven-aged tires has been shown*

The tires were filled with 50/50 N_2/O_2, air or N_2 and oven-aged for 5 weeks @ 65°C

They were then tested according to the FMVSS 139 Endurance and Low Pressure Test (to failure or 35.5 hours stop-finish)

50/50 N_2/O_2 had a significant deleterious effect. Tires aged with N_2 or air inflation all passed test @ 35.5 hrs

** N. Tokita, W.D. Sigworth, G.H. Nybakkan, G.B. Ouyang, "Long-Term Durability of Tires," Paper 18D17, Proceedings of the International Rubber Conference, Kyoto, 1985, p. 672-679.*

J. M. Baldwin, D.R. Bauer, and K.R. Ellwood, "Effects of Nitrogen Inflation on Tire Aging and Performance," Paper 2, presented at Rubber Division, ACS, Grand Rapids, MI, May 17-19, 2004.

U. Karmakar, "Effect of Nitrogen Purity on the Oxidation of Belt Coat Compound," presented at the International Tire Exposition and Conference, Akron, OH, September, 2006.

Conclusion (I)

- **In laboratory testing, tires inflated with 94-99% N_2 showed a 34% reduction in pressure loss versus tires inflated with air (78% N_2)**
  - Based on reduced O_2 observed for in-service tires, the benefits of N_2 in service would be significantly reduced
  - Tires inflated with N_2 above 97% purity showed diffusion of O_2 into the tire at 90 days
- **Similar reduction in IPLR for tires inflated with N_2 during 700-hour dynamic, loaded roadwheel test**
- **Innerliner composition and initial inflation pressure had no significant effect on reduction of IPLR for N_2 versus air**

Conclusions (II)

- **Tire inflation with N_2 versus air had no significant effect on rolling resistance**
  - Benefits of N_2 will likely be indirect from improved retention of inflation pressure over time
- **Laboratory tire endurance after oven aging was reduced by high O_2 content in inflation gas during oven aging**
  - Tires inflated with air or N_2 during aging completed the post-oven 35.5 hour test with no failures
  - Previous studies have shown benefits for tire roadwheel endurance when tires inflated with N_2 during aging