THE EFFECTS OF INFLATION GAS ON TIRE LABORATORY TEST PERFORMANCE

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The Effects of Inflation Gas on Tire Laboratory Test Performance

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Nitrogen Inflation of Pneumatic Tires

- Inflation of tires with N₂ 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 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
- An average of 117 people died each day in motor vehicle crashes in 2006 — one every 12 minutes
- 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*
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 any 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 related to the nitrogen-to-oxygen ratio?
Testing

- Twenty-five passenger or light truck tire models were inflated with:
  - Shop air with air line dryer
  - Dry N₂ 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
  - Material properties
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

- Tires lose inflation gases continuously, since rubber compounds are permeable to gas molecules and losses 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.
Minimum sample of 2 tires per model

Clean painted steel (preferred) wheel or other material that has been leak checked

Rim size per Tire & Rim Association or other standards organization (prefer measuring rim)

Rim seat diameter must be within tolerances from standards (confirmed with ball tape)

Pressure transducer or gauge

Two metal valves or “T” valve + metal valve
ASTM F1112-06 Inflation Pressure Loss Rate (IPLR)

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)
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 21°C ± 3°C

The pressure and conditions are monitored over time
  - NHTSA testing used 90 days with continuous monitoring of the pressure via computer interface
    - Per the standard the first 30 days data was discarded

Data is then corrected to a standard temperature and barometric pressure
  - 21°C and 101.3 kPa
Example Data Output

Rate stabilizes after 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?**

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

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>27</td>
<td>56.41</td>
<td>2.089</td>
<td>22.56</td>
<td>&lt;.0001</td>
<td>0.902</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>6.11</td>
<td>0.092</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>93</td>
<td>62.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**Inflation Gas and Tire Type are Significant Variables**
IPLR with Air vs. N₂ Inflation

17 Different Models of Tires

Average IPLR for N₂ was 66% of Air
Tire Parameters

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

- Of the variables studied, innerliner composition and minimum thickness had most significant effect on IPLR
  - Filler and volatiles had significant, but lesser effects

- Analysis of difference in IPLR between air and N₂ (IPLR\textsubscript{air} – IPLR\textsubscript{nitrogen}) by tire type
  - No significant effect of any construction parameter
  - No significant effect of initial inflation pressure
    - Passenger / LT tires

Benefits of Nitrogen Inflation on IPLR
Appear to be Applicable to All Tire Types
Nitrogen Inflation & Oxygen Concentration Equipment

Balston®
72-730
Oxygen Analyzer
Accurate to <0.1% O₂
O₂ Migration During Test

Change in Percent Oxygen Concentration During IPL Test Versus Starting Oxygen Concentration

\[ y = -0.0016x^2 - 0.0519x + 0.2166 \]

\[ R^2 = 0.9156 \]
Faster migration of O\textsubscript{2} changes mixture of gas during 90-day test
- Tires inflated with air lost average of 1.5\% O\textsubscript{2}
- Tires inflated with N\textsubscript{2} lost or gained O\textsubscript{2} to approach equilibrium partial pressure

O\textsubscript{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 % $O_2$

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.
### O₂ Level Significantly Reduced In-Service

<table>
<thead>
<tr>
<th>Oxygen Range (% of inflation gas)</th>
<th>Number of Tires</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 ➔ 11</td>
<td>4</td>
</tr>
<tr>
<td>11.1 ➔ 13</td>
<td>18</td>
</tr>
<tr>
<td>13.1 ➔ 15</td>
<td>18</td>
</tr>
<tr>
<td>15.1 ➔ 17</td>
<td>17</td>
</tr>
<tr>
<td>17.1 ➔ 19</td>
<td>14</td>
</tr>
<tr>
<td>19.1 ➔ 20.0</td>
<td>5</td>
</tr>
</tbody>
</table>

**Indicates Reduced Potential Benefits for N₂ Inflation in Normal Tire Service**

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.79</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

$IPLR_{avg} = 1.4$

$IPLR_{avg} = 1.8$

$IPLR_{avg} = 2.1$
**Dynamic Inflation Pressure Loss – Roadwheel Testing**

*Modified LTDE Test: Inflation Pressure vs. Roadwheel Hours (Capped Inflation - Pressure Corrected to 311.15 K)*

Inflation Pressure Loss During Roadwheel Testing Was 37% Less for Tires Inflated with N₂ vs. Tires Inflated with Air
Change in %O₂ During Dynamic Loaded Operation

Modified LTDE Test: Percent Oxygen of Inflation Gas vs. Roadwheel Hours

Higher %O₂ Gas Diffuses More Rapidly During Dynamic Roadwheel Testing
Does N\textsubscript{2} Have a Direct Effect on Rolling Resistance?

- 24 Tires were compared for Rolling Resistance, either inflated with N\textsubscript{2} or Air
  - SAE J1269 Single-Point Test
  - Average Rolling Resistance:
    - Air = 12.80 pounds ±0.38
    - N\textsubscript{2} = 12.65 pounds ±0.44

No Direct Effect Observed for N\textsubscript{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

The benefits of N₂ inflation on oven-aged tires has been shown*

The tires were filled with 50/50 N₂/O₂, air or N₂ 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 N₂/O₂ had a significant deleterious effect. Tires aged with N₂ or air inflation all passed test @ 35.5 hrs


In laboratory testing, tires inflated with 94-99% N\textsubscript{2} showed a 34% reduction in pressure loss versus tires inflated with air (78% N\textsubscript{2})
  - Based on reduced O\textsubscript{2} observed for in-service tires, the benefits of N\textsubscript{2} in service would be significantly reduced
  - Tires inflated with N\textsubscript{2} above 97% purity showed diffusion of O\textsubscript{2} into the tire at 90 days

Similar reduction in IPLR for tires inflated with N\textsubscript{2} during 800-hour dynamic, loaded roadwheel test

Innerliner composition and initial inflation pressure had no significant effect on reduction of IPLR for N\textsubscript{2} versus air
Conclusions (II)

- **Tire inflation with N\textsubscript{2} versus air had no significant effect on rolling resistance**
  - Benefits of N\textsubscript{2} will likely be \textbf{indirect} from improved retention of inflation pressure over time

- **Laboratory tire endurance after oven aging was reduced by high O\textsubscript{2} content in inflation gas during oven aging**
  - Tires inflated with air or N\textsubscript{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\textsubscript{2} during aging