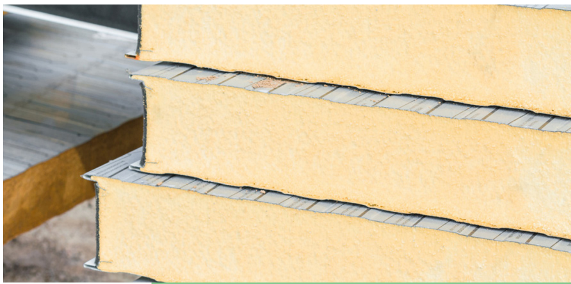
Polyurethane rigid foam Portfolio

Product Overview

Cardolite
Chemistry for Tomorrow



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ABOUT US

R&D, Management, and Sales

Manufacturing, R&D and Sales

Sales

Cardolite uses CNSL derivatives as key building blocks for most of its products to achieve unprecedented performance that solves today's problems in a sustainable manner.

Over 35 years supplying high quality specialty chemicals derived from Cashew Nutshell Liquid (CNSL), a renewable, non-food chain material.

Dedicated sales force with local representation in over 30 countries. Warehouses set up in the USA, Latin America, Europe, China and India.

The most advanced CNSL manufacturing facilities in the world located in Zhuhai (Guangdong), China and Mangalore, India

MARKETS & PRODUCT LINES

Cardolite continues to invest heavily on innovation that leverages the unique properties of CNSL technology. Cardolite operates advanced research and technical service laboratories in the USA, China and India that use CNSL as a primary building block to develop specialty materials with demonstrated advantages over some traditional petro-based chemistries.

Product Lines for Foam

- Polyol and Diol Resins
  - CNSL Modified
  - Novolacs and Aromatics
  - Mannichs
  - Polyethers
  - Polyesters
- Diluents
- Surfactants

Other Product Lines

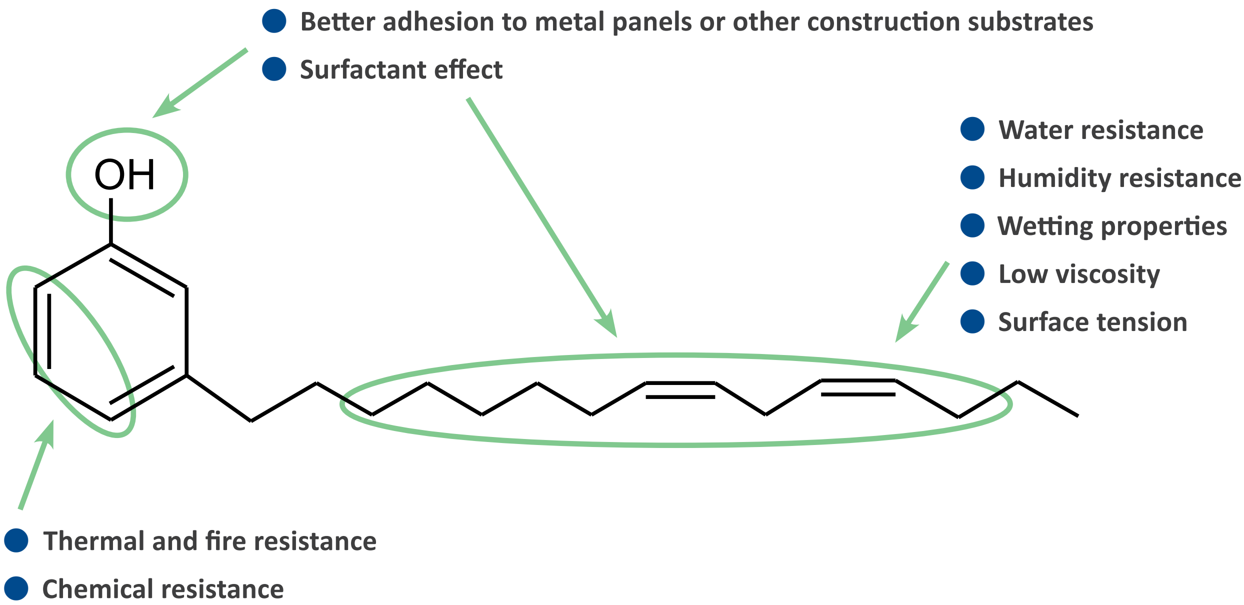
- NCO Blocking Agents
- Hydrocarbon Resins
- Resin Diluents and Modifiers
- Epoxy Curing Agents
- Friction Particles and Resins

Markets

- Rigid and Flexible Foams
- Coatings
- Adhesives and Sealants
- Composites
- Automotive Brakes
- Bioplastics and Biopolymers

CNSL TECHNOLOGY

Cardanol is a unique natural phenolic material obtained by distilling CNSL and serves as the primary building block for Cardolite polyols and derivatives. The molecule is composed of an aromatic ring with an OH group and a long aliphatic side chain, which bring valuable intrinsic benefits to foams.



RENEWABLE

From the beginning, Cardolite products have been based on cashew nutshell liquid, a natural, non-food chain, and annually renewable biomaterial. The technology has been widely adopted because there are inherent performance benefits gained from using this starting raw material without sacrificing performance or cost.

- Annually renewable with high biocontent derivatives
- Low viscosity for low or zero V.O.C.
- Cost effective
- Does not interfere with the food chain
- High performance
- Better labeling compared to phenol-based materials

CNSL POLYOL TECHNOLOGY

Cardolite polyols based on Cashew Nutshell Liquid (CNSL) Technology are functionalized to provide specific handling and performance properties. A wide range of viscosities, hydroxyl values, molecular weights, and functionalities can be achieved with CNSL technology to meet different application requirements in rigid foams. The intrinsic benefits inherited from CNSL technology translate into polyols with fast reactivity, good compression strength and fire resistance, hydrophobicity, and good compatibility with various blowing agents. Typical properties and recommended uses for the different CNSL polyol families follow.

Novolac and Aromatic Polyols

- Typically low in viscosity and high in functionality
- Very high in biocontent (≥ 80%)
- Offer high compression strength
- Provide aromaticity for excellent fire resistance
- Good partial replacements for polyether polyols in spray foams, insulation panels and boardstocks, pour-in-place and injection foams for improved fire resistance and reactivity
- Suitable replacements for aliphatic polyester polyols in high index PIR foams to improve compression strength and maintain excellent fire properties and reactivity

Mannich Polyols

- Wide range of hydroxyl values
- High in biocontent (> 50%)
- Very fast reactivity
- Provide aromaticity for excellent fire resistance
- Excellent replacement for petrochemical-based Mannich polyols in spray foams, insulation panels and boardstocks, pour-in-place and injection foams with similar or better properties
- Suitable replacements for aromatic polyester polyols in PIR foams while maintaining excellent reactivity, fire resistance and mechanical properties

Diols

- Low hydroxyl values
- High in biocontent (> 50%)
- Suitable as building blocks for prepolymers and modifiers for PUR foams
- Suitable for use in flexible foams

Table 1: CNSL Aromatic, Novolac and Specialty Polyols Typical Properties

Product	Color[1] (Gardner)	Avg. OH value[2] (mg KOH/g)	Viscosity[3] 25°C (cPs)	Avg. OH Func.[4]	Bio-content[5] (%)	Description	Foam Applications
LITE 9001	6	175	2,000	4.3	88	- Light color version of NX-9001 - Very fast cure - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9001	18	175	2,000	4.3	88	- Excellent alkaline resistance - Low water absorption - Good mechanical properties and fire resistance - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9001LV	18	175	1,000	3.8	91	- Low viscosity version of NX-9001 - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9004	18+	198	5,000	4.1	93	- REACH compliant version of NX-5285 - Higher viscosity - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-5285	18+	200	2,500	3.5	93	- Fast cure - Cost effective - Low water absorption - Good mechanical properties and fire resistance - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
LITE 9006	14	175	2,250	3.3	95	- Light color version of NX-9006 - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9006	18	190	3,000	4.4	95	- Slower cure - Cost effective - Low water absorption - Good mechanical properties and fire resistance - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9007	14	175	2,900	3.3	80	- Higher strength and elongation - Good water resistance	- Spray foam - Continuous PUR panels - Rigid boardstocks - High-med index PIR
NX-9008	10	340	3,000	3.0	61	- High strength polyether polyol - Good stability in HFO blown formulas	- Spray foam - Continuous PUR panels - Rigid boardstocks

[1]ASTM D1544, [2]ASTM D4274, [3]ASTM D2196 at 25ºC, [4]Average estimated value by GPC.
[5]Calculated bio-content values are estimated based on composition and process parameters. They have not been validated by ASTM D6866 measurements and should be considered as theoretical estimates only.

Table 2: CNSL Mannich Polyols Typical Properties

Product	Color[1] (Gardner)	Avg. OH value[2] (mg KOH/g)	Viscosity[3] 25°C (cPs)	Avg. OH Func.[4]	Bio-content[5] (%)	Description	Foam Applications
NX-9101	15	430	2,500	3.0	72	- Low viscosity - Medium-high reactivity - Good fire performances - Good thermal stability	- Spray systems - PUR systems - Pour-in-place applications
NX-9102	15	445	7,750	4.0	78	- Medium-high reactivity - Good fire performances and thermal stability - Good mechanical properties	- Spray systems - Pour-in-place applications
NX-9103	15	475	10,500	4.0	60	- Medium-high reactivity - Good fire performances and thermal stability - Good mechanical properties	- Spray systems
NX-9104	15	245	5,500	3	59	- Mannich polyol with best stability in HFO blown formulas - Medium reactivity - Good fire performances and thermal stability - Good mechanical properties	- Spray systems - Continuous PUR/PIR panels - Pour-in-place applications
NX-9106	15	310	2,400	3.7	80	- Low viscosity - Medium reactivity - Good fire performances - Good thermal stability	- Spray systems - PUR systems - Pour-in-place applications

Table 3: CNSL Diols Typical Properties

Product	Color[1] (Gardner)	Avg. OH value[3] (mg KOH/g)	Viscosity[2] 25°C (cPs)	Avg. OH Func.[4]	Bio-content[5] (%)	Description	Foam Applications
NX-9201	14	75	1,400	~2.0	87	- Low-medium viscosity CNSL-polyester diol polyol - Low reactivity - Good thermal stability	- Spray systems - PUR systems - Pour in place applications - Flexible Foam
NX-9203	14	85	3,000	~2.0	69	- Low-medium viscosity CNSL-polyester diol polyol - Low reactivity - Good thermal stability	- Spray systems - PUR systems - Pour in place applications - Flexible foam

CNSL POLYOLS
COMPATIBILITY

Compatibility with Other Polyols

The compatibility of novel CNSL and standard petro-based polyols is shown in Table 4. Several blends of CNSL polyols with petro-based Mannich polyols, aliphatic and aromatic polyester polyols, and polyether polyols were monitored for their stability and ranked based on phase separation extent. CNSL-based polyols, even if characterized by a high hydrocarbon content, contain enough polar groups (e.g. amino, hydroxyl, esters) to guarantee excellent compatibility with polyether polyols and petro-based Mannichs.

On the contrary, as seen with other natural oil polyols, CNSL polyols show limited miscibility with polyester polyols (both aliphatic and aromatic). However, this limitation can be easily overcome by properly tuning the composition of the polyurethane formula. As an example, a polyether polyol may be used as a co-polyol, balancing the CNSL polyol/polyester polyol ratio. Other options include the use of non-ionic surfactants, emulsifiers or blowing agents with a solvent effect (e.g. methyl formate).

Table 4: Compatibility of Polyols

	CNSL-Based Polyols				
Petro-Based Polyol	NX-9101	NX-9102	NX-9104	NX-9001	NX-9006
Mannich (OH 425)	++++++	++++++	++++++	++++++	++++++
Aromatic Polyester (OH 240)	+	+	+	+	+++++
Aliphatic Polyester (OH 350)	+	+	+	+	+++++
Propoxylated Sorbitol Polyether (OH 300)	++++++	++++++	++++++	++++++	++++++
Alkoxylated Sucrose Based Polyether (OH 360)	++++++	++++++	++++	++++++	++++++
Alkoxylated Sucrose/DEG Based Polyether (OH 440)	++++++	++++++	+++++	++++	++++++
Ethoxylated/Propoxylated Glycerine Based Polyether (OH 33)	++++++	++++++	++++	++++++	++++++
PPG 1000 (OH 114)	++++++	++++++	++++++	++++++	++++++
Propoxylated Glycerine Polyether Polyol (OH 156)	++++++	++++++	++++++	++++++	++++++
Propylene Oxide/Ethylene Oxide Based Polyether Polyol (OH 48)	++++++	++++++	++++++	++++++	++++++

++++++ clear blend at both 25/75 and 50/50 CNSL/petroleum ratio
+++++ clear blend at 50/50, but phase separation at 25/75 CNSL/petroleum ratio
++++ clear blend at 50/50 and cloudy, but non-separating blend at 25/75 CNSL/petroleum ratio
+++ cloudy blend at 50/50, but phase separation at 25/75 CNSL/petroleum ratio
++ cloudy blend at 25/75, but phase separation at 50/50 CNSL/petroleum ratio
+ phase separation at both 25/75 and 50/50 CNSL/petroleum ratio

Compatibility with Blowing Agents

The compatibility of CNSL-based polyols with standard blowing agents for PUR spray and PIR polyurethane foams (e.g. n-pentane, HFC, methyl-formate, HFO) is shown in Table 5. Polyols must exhibit good compatibility with the blowing agent of choice to ensure adequate final foam properties and B-part stability.

This miscibility study has been accomplished by blending polyols (both CNSL- and petro-based) and blowing agents in a 60/40 weight ratio respectively, in tightly closed graduated containers, recording the appearance of the mixtures after 24 hours at room temperature. In case of phase separation, the miscibility has been determined by measuring the height of the blowing agent phase: since the density is known, the amount (in grams) of the blowing agent dissolved into the polyol-phase can be easily recovered. Results of ≥ 40 indicate full miscibility.

Cardanol-based polyols demonstrated excellent miscibility with methyl-formate, n-pentane and HFO, better than petro-based Mannich and polyester polyols, while the compatibility with HFC is comparable to commercial references.

Table 5: Compatibility with Blowing Agents

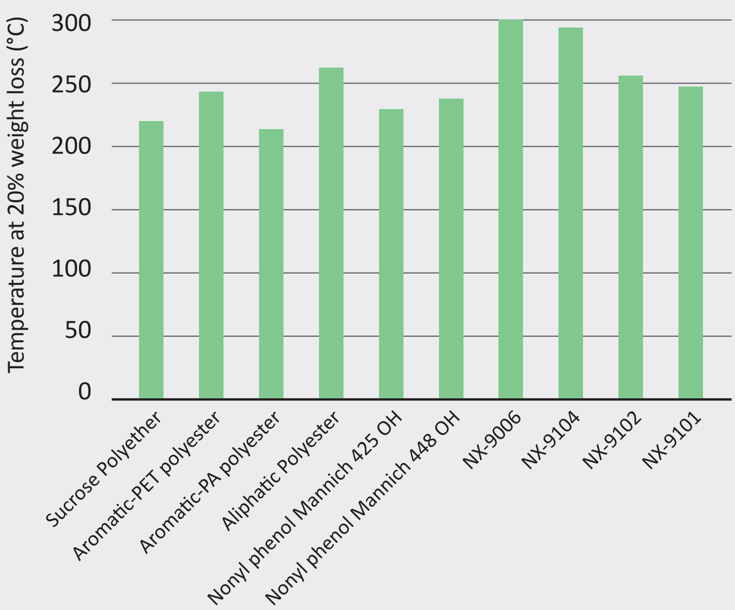
Polyol Type	Storage Conditions	Polyol/ methyl-formate (60/40 w/w)	Polyol/HFC (60/40 w/w)	Polyol/ n-pentane (60/40 w/w)	Polyol/HFO (60/40 w/w)
		Maximum Wt. for Single Phase Solution (%)			
NX-9101	24 h at RT	≥ 40	~ 10	≥ 40	≥ 40
NX-9102		≥ 40	~ 12	≥ 40	≥ 40
NX-9104		≥ 40	~ 10	≥ 40	≥ 40
Petro-Mannich polyol (OH 425)		≥ 40	~ 25	~ 4	≥ 40
Petro-Mannich polyol (OH 450)		≥ 40	~ 26	~ 2	≥ 40
NX-9006		≥ 40	~ 6	≥ 40	≥ 40
NX-9001		≥ 40	~ 6	≥ 40	≥ 40
Aromatic-PA polyester polyol (OH 240)		≥ 40	~ 6	~ 2	~ 9
Aromatic-PET polyester polyol (OH 240)		≥ 40	~ 12	~ 2	~ 25
Aliphatic polyester polyol (OH 350)		≥ 40	~ 14	~ 1	~ 23
Polyether polyol (OH 360)		≥ 40	≥ 40	≥ 40	≥ 40

CNSL POLYOLS PERFORMANCE
THERMAL RESISTANCE

Thermal Resistance

CNSL-based polyols are expected to provide good thermal resistance due to the aromatic ring in their backbone. Thermal gravimetric results shown in the TGA graph on the right confirm that in average, CNSL-based polyols can withstand higher temperatures than typical polyether polyols and petro-based Mannich polyols. CNSL-based polyols also performed similarly or better than aliphatic and aromatic polyesters. Results were reported based on the temperature required for a 20% polyol weight loss.

Graph 1: TGA Analysis



Aromaticity

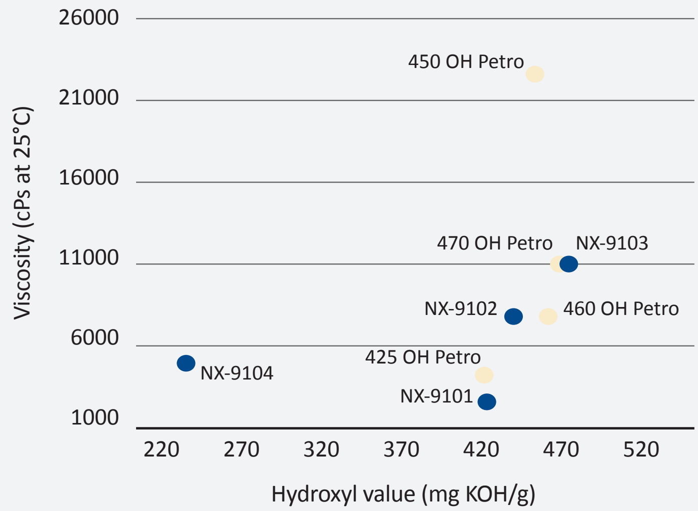
The aromatic content of CNSL-based polyols can be calculated based on composition and manufacturing process for comparison purposes to other polyol chemistries. In general, CNSL-based Novolacs have similar aromatic content to aromatic polyester polyols (20-23%) and CNSL-based Mannich polyols have comparable aromatic content to petro-based Mannich polyols (16-19%). Specific values can be obtained as needed.

CNSL MANNICH POLYOLS AS
PETROCHEMICAL-BASED MANNICH POLYOLS REPLACEMENTS

Handling and Formulating Properties

CNSL-based Mannich polyols are lower in viscosity and have a broader range of hydroxyl values than petro-based analogues. Being compatible with standard polyols and blowing agents, Cardolite CNSL-based Mannich polyols are an excellent bio-based replacement to conventional petro-based Mannich polyols with similar or better performance. Moreover, CNSL Mannich polyols offer excellent field processing, good dimensional stability, low friability, good flow, very uniform fine cell structure and high closed cell content.

Graph 2: Viscosity vs. Hydroxyl Values of Mannich Polyols



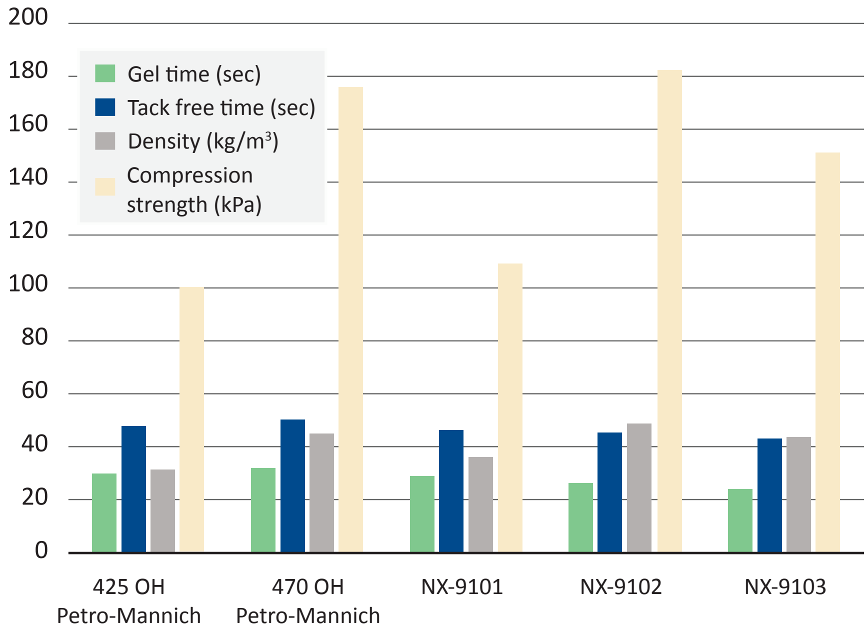
Reactivity and Compression Strength

Due to the nature of the hydroxyl groups within each derivative, CNSL-based Mannich polyols exhibit reaction profiles comparable or faster than standard commercial Mannich polyols, thus being suitable for the majority of rigid polyurethane systems, including PIR systems. Moreover, the combination of aromatic content and long alkenyl chain of CNSL Mannich polyols delivers comparable or superior compression strength versus petro-based Mannich polyols at similar density levels in PUR foams.

Table 6: Formulation for Spray Foam

Formulation A	Parts
Sucrose/glycerine based polyether polyol (360OH)	65
Aromatic polyester polyol (315 OH)	25
Mannich polyol	10
TCPP	20
Water	1.5
Blowing catalyst	1.2
Gelling catalyst	1.2
Silicone surfactant	1.4
Solkane 365/227	14
pMDI index	120

Graph 3: Formulation A Reaction Profile & Mechanical Properties



Limiting Oxygen Index

O_2

Limiting Oxygen Index percent was measured for Formulation A as an indication of flammability. CNSL-based Mannich polyols NX-9101 and NX-9102 performed similarly or slightly better than petro-based Mannichs in Formulation A as indicated in Table 7.

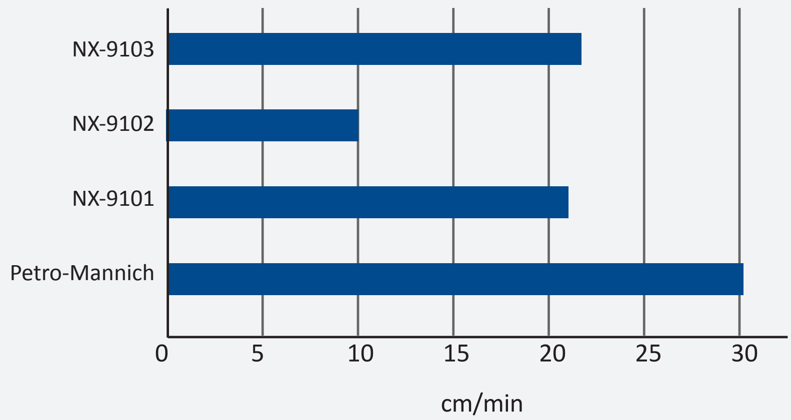
Table 7: LOI for Formulation A

Formulation A - Mannich Polyol Used at 10 parts	Limiting Oxygen Index %
NX-9101	24.8
NX-9102	24.7
Petro-Mannich polyol (425 OH)	23.8
Petro-Mannich polyol (470 OH)	24.2

Fire Resistance

The high aromatic content of CNSL-based Mannich polyols and overall composition results in excellent fire resistance properties that can be seen by lower burning rates and less flammability than petro-based counterparts as demonstrated in Graph 4.

Graph 4: Formulation B Burning Rate for Different Mannich Polyols



Cost Reduction

The surfactant-like properties from CNSL derivatives and their inherent fast reactivity allows foam formulators to reduce the use of expensive additives such as blowing and gelling catalysts as well as surfactants as shown in Table 8. The CNSL-based foam shows similar dimensions and cell structure to the reference.

Table 8: Formulation For Appliances With Reduced Cost

Formulation B	Reference Parts	CNSL Modified Parts	Change %
Sucrose/glycerine based polyether polyol (490 OH)	18.1	18.1	n/a
Aromatic polyester polyol (240OH)	7.2	7.2	n/a
Mannich polyol	10.9	10.9 (NX-9101)	n/a
TCPP	2.36	2.36	n/a
Water	0.64	0.68	+6.25
Blowing catalyst	0.07	0.028	-60
Gelling catalyst	0.37	0.24	-35
Silicone surfactant	0.71	0.55	-22.5
Solkane 365/227	7	7	n/a
pMDI index	115	115	n/a

CNSL-BASED POLYOLS IN SPRAY FOAM FORMULATIONS

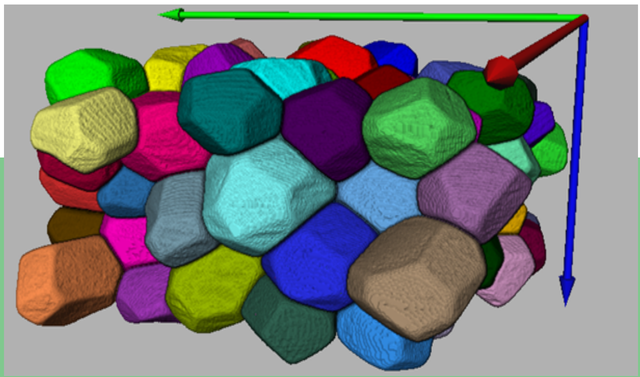
Spray Foam Closed Cell

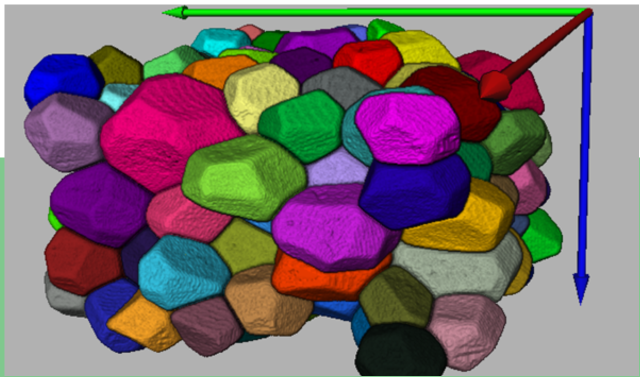
Table 9 shows two comparisons between CNSL- and Petro-based Mannich polyols in systems using Solstice LBA as the blowing agent in closed cell spray foam formulations.

Formulations C and D have high amounts of Mannich polyols and reactivity profile results indicate NX-9101 is faster than the hydroxyl equivalent petro-Mannich given that a reduction in catalyst amount in formulation D did not affect the reaction times. Moreover, both formulations provided similar density, compression strength and thermal resistance. Images of both foams obtained at very high resolution (synchrotron light) indicate NX-9101 provided good cell size that should yield high insulation properties (Image 1).

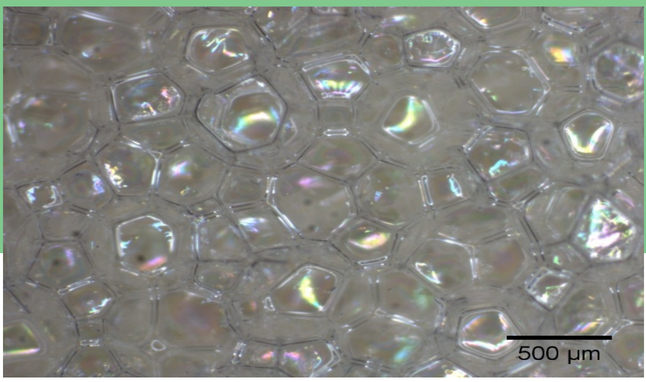
Formulations E and F use Mannich polyols with a sightly higher hydroxyl value in lower amounts. Results showed NX-9102 is faster than the equivalent petro-Mannich for a similar density foam and compression strength. Thermal conductivity at low and room temperatures as well as the limiting oxygen index were very similar for both formulations, with values indicating good insulation and fire resistance properties. NX-9102 delivered slightly better thermal resistance than the petro-analogue.

Image 1: Synchrotron Light Images of Formulations C and D





Formulation C number of cells per unit: 100



Formulation D number of cells per unit: 160

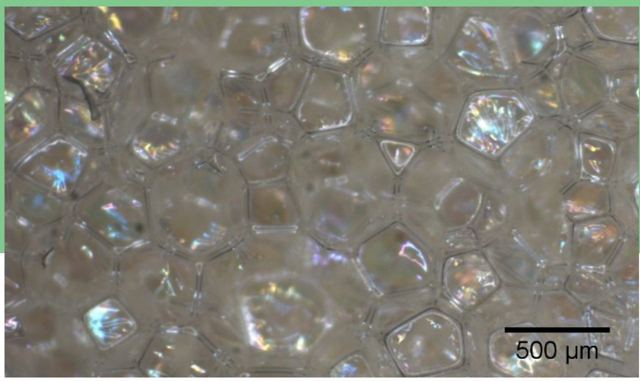


Table 9: Spray Foam Closed Cell Formulations with NX-9101 and NX-9102

<table>
<tr><th colspan="2">Components (parts)</th><th>Formulation C</th><th>Formulation D</th><th>Formulation E</th><th>Formulation F</th></tr>
<tr><td colspan="2">Polyether polyol (OH 490)</td><td colspan="2">15</td><td></td><td></td></tr>
<tr><td colspan="2">Aromatic -PA polyester polyol (OH 240)</td><td colspan="2">20</td><td colspan="2">25</td></tr>
<tr><td colspan="2">Glycerine</td><td colspan="2">2</td><td></td><td></td></tr>
<tr><td colspan="2">Petro-Mannich polyol (OH 425)</td><td>35</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">NX-9101</td><td></td><td>35</td><td></td><td></td></tr>
<tr><td colspan="2">Polyether polyol (OH 360)</td><td></td><td></td><td colspan="2">65</td></tr>
<tr><td colspan="2">High viscosity brominated diol</td><td></td><td></td><td colspan="2">8</td></tr>
<tr><td colspan="2">Petro-Mannich polyol (OH 448)</td><td></td><td></td><td>10</td><td></td></tr>
<tr><td colspan="2">NX-9102</td><td></td><td></td><td></td><td>10</td></tr>
<tr><td colspan="2">TCPP</td><td colspan="2">11</td><td colspan="2">20</td></tr>
<tr><td colspan="2">Dabco LK-221E</td><td colspan="2">0.5</td><td></td><td></td></tr>
<tr><td colspan="2">Dabco DC-193</td><td colspan="2">1</td><td colspan="2">1.4</td></tr>
<tr><td colspan="2">Water</td><td colspan="2">2</td><td colspan="2">1.5</td></tr>
<tr><td colspan="2">Polycat 203</td><td>1</td><td>0.9</td><td colspan="2">1.2</td></tr>
<tr><td colspan="2">Dabco 33LV</td><td>0.5</td><td>0.3</td><td colspan="2">1.2</td></tr>
<tr><td colspan="2">Solstice LBA</td><td colspan="2">12.5</td><td colspan="2">14</td></tr>
<tr><td colspan="2">NCO Index</td><td colspan="2">110</td><td colspan="2">120</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">Mix Time (sec)</td><td>3</td><td>3</td><td>8</td><td>8</td></tr>
<tr><td colspan="2">String Time (sec)</td><td>14</td><td>13</td><td>51</td><td>40</td></tr>
<tr><td colspan="2">Tack Free Time (sec)</td><td>25</td><td>23</td><td>99</td><td>75</td></tr>
<tr><td colspan="2">Density, lb/ft^3 (kg/m^3)</td><td>1.68 (27)</td><td>1.67 (26.9)</td><td>2.66 (42.6)</td><td>2.65 (42.5)</td></tr>
<tr><td colspan="2">Compression strength, psi (kPa)</td><td>16.7 (115)</td><td>14.6 (101)</td><td>25.8 (178)</td><td>26.9 (186)</td></tr>
<tr><td rowspan="2">Thermal conductivity (l),
Btu in/ft² hour °F (mW/mK)</td><td>24 °C</td><td>n.a.</td><td>n.a.</td><td>0.171 (24.7)</td><td>0.173 (24.9)</td></tr>
<tr><td>10 °C</td><td>n.a.</td><td>n.a.</td><td>0.162 (23.4)</td><td>0.164 (23.6)</td></tr>
<tr><td colspan="2">Limiting Oxygen Index (%)</td><td>n.a.</td><td>n.a.</td><td>25</td><td>24.9</td></tr>
<tr><td colspan="2">Temperature at 20% weight loss (°C, TGA, air flow, scan from 25-600 °C)</td><td>293.7</td><td>295.5</td><td>281.3</td><td>292.3</td></tr>
</table>

Reactivity and Compression Strength

NX-9104 can be used as replacement for aromatic polyester polyols in polyurethane spray foams as illustrated by formulation G. In comparison to reference A, formulation G shows improved fire resistance according to DIN4102 B2 test results and lower water absorption due to the hydrophobic and aromatic backbone of NX-9104. The NX-9104-based foam showed similar density and good compression strength in both directions. The slightly slower reactivity shown by NX-9104 can be addressed by minor adjustments in the formulation as demonstrated by formulation H compared to reference B. In this case, string time and tack free times of both formulations are similar, and as seen with previous results, the formulation based on NX-9104 showed better fire resistance and lower water absorption.

Table 10: Spray Foam Closed Cell Formulation with NX-9104

Components (parts)	Reference A				Formulation G			
Aromatic polyester polyol (OH 250)	35							
Sucrose-based polyether (OH 360)	20				20			
Triethanolamine-based polyol (OH 440)	45				45			
NX-9104					35			
Triethanolamine	1.5				1.5			
TCPP	25				25			
TEP	5				5			
DABCO T120	0.3				0.3			
Polycat 203	1.2				1.2			
DMCHA	1				1			
DABCO DC193	2.5				2.5			
Water	2.1				2.2			
Solstice LBA	12				12			
pMDI Index	120				120			
Mix Time (sec)	5				5			
String Time (sec)	22				24			
Tack Free Time (sec)	30				33			
Density (Kg/m³)	37.0				36.7			
Compression strength, parallel (kPa)	244				266			
Compression strength, perpendicular (kPa)	290				264			
Tg (°C)	139.4				157.5			
Water absorption, % (4 dd @ RT)	0.05				0.01			
DIN 4102 (Average on 2 specimens)	**Surface**		**Edge**		**Surface**		**Edge**	
	Time (sec)	Length (mm)	Time (sec)	Length (mm)	Time (sec)	Length (mm)	Time (sec)	Length (mm)
	1	145	2	150	1	133	1	125

Table 11: Spray Foam Closed Cell Formulation with NX-9104

<table>
<tr><th>Components (parts)</th><th colspan="4">Reference B</th><th colspan="4">Formulation H</th></tr>
<tr><td>Sucrose-based polyether (OH 360)</td><td colspan="4">35</td><td colspan="4">35</td></tr>
<tr><td>Aromatic polyester polyol (OH 250)</td><td colspan="4">25</td><td colspan="4"></td></tr>
<tr><td>Petro-mannich polyol (OH 448)</td><td colspan="4">40</td><td colspan="4">40</td></tr>
<tr><td>Glycerol</td><td colspan="4"></td><td colspan="4">1</td></tr>
<tr><td>NX-9104</td><td colspan="4"></td><td colspan="4">24</td></tr>
<tr><td>TCPP</td><td colspan="4">15</td><td colspan="4">15</td></tr>
<tr><td>TEP</td><td colspan="4">5</td><td colspan="4">5</td></tr>
<tr><td>Water</td><td colspan="4">1.9</td><td colspan="4">1.9</td></tr>
<tr><td>T12</td><td colspan="4">0.5</td><td colspan="4">0.5</td></tr>
<tr><td>DABCO 33LV</td><td colspan="4">1.2</td><td colspan="4">1.2</td></tr>
<tr><td>DABCO DC193</td><td colspan="4">1.4</td><td colspan="4">1.4</td></tr>
<tr><td>Cyclopentane</td><td colspan="4">12</td><td colspan="4">12</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>pMDI Index</td><td colspan="4">120</td><td colspan="4">120</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Mix Time (sec)</td><td colspan="4">5</td><td colspan="4">5</td></tr>
<tr><td>String Time (sec)</td><td colspan="4">20</td><td colspan="4">20</td></tr>
<tr><td>Tack Free Time (sec)</td><td colspan="4">25</td><td colspan="4">23</td></tr>
<tr><td>Density (Kg/m³)</td><td colspan="4">31.0</td><td colspan="4">31.9</td></tr>
<tr><td>Compression strength, parallel (kPa)</td><td colspan="4">116</td><td colspan="4">118</td></tr>
<tr><td>Compression strength, perpendicular (kPa)</td><td colspan="4">149</td><td colspan="4">132</td></tr>
<tr><td>Water absorption, % (4 dd @ RT)</td><td colspan="4">2.85</td><td colspan="4">0.02</td></tr>
<tr><td rowspan="3">DIN 4102
(Average on 2 specimens)</td><th colspan="2">Surface</th><th colspan="2">Edge</th><th colspan="2">Surface</th><th colspan="2">Edge</th></tr>
<tr><td>Time (sec)</td><td>Length (mm)</td><td>Time (sec)</td><td>Length (mm)</td><td>Time (sec)</td><td>Length (mm)</td><td>Time (sec)</td><td>Length (mm)</td></tr>
<tr><td>1.5</td><td>140</td><td>1.5</td><td>150</td><td>1</td><td>120</td><td>1</td><td>115</td></tr>
</table>

Table 12: Spray Foam Closed Cell Formulation with NX-9008

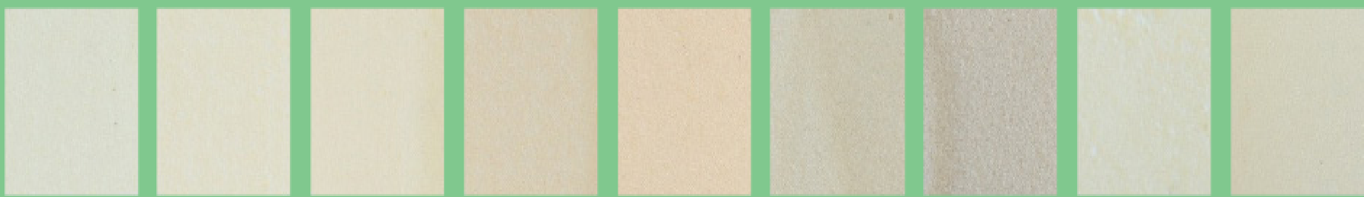
Components (parts)	Reference C	Formulation I
Propoxylated sorbitol polyether polyol (OH 300)	40	0
Aromatic PET polyester polyol (OH 240)	25	25
Propoxylated Mannich polyol (OH 448)	35	35
NX-9008	0	40
TCPP	20	20
Water	1.90	1.75
DABCO T12	0.15	0.15
DABCO 33LV	1	1
Tegostab B8461	1.4	1.4
Solkane 365/227	12	12
pMDI Index	110	110
Mix time (sec)	5	5
String time (sec)	17	16
Track free time (sec)	32	29
Density (kg/m³)	39.7	40.1
Compression strength, parallel (kPa)	169	175
UL-94, vertical (after flame, sec)	V1 (11.8)	V0 (6.7)

NX-9008 is a suitable, biorenewable replacement for polyether polyols in polyurethane rigid foams. In the example shown in Table 12, a propoxylated sorbitol polyether polyol was fully replaced by NX-9008 in formulation I. Formulation I provided better fire resistance according to UL 94 test results and good mechanical properties, density and reactivity.

CNSL-BASED POLYOLS AS ADDITIVES IN SPRAY FOAMS

Cardolite's high biocontent aromatic and novolac type polyols are excellent options for polyurethane rigid foams. They can be incorporated at low to higher levels depending on application requirements to increase biocontent and lower water absorption while maintaining good properties and minimizing costs. Spray foam formulations displayed on Table 13 show that CNSL-based polyols can be partial replacements for aromatic polyester polyols without the need to reformulate the polyurethane foam. CNSL-based polyols provide good performance overall. Our evaluations demonstrated that at 5%, NX-9001 and LITE 9006 provided an improvement in UL 94 performance. In addition, NX-9001 showed excellent compression strength and similar reactivity to standard aromatic polyol. Foams modified by NX-9006 delivered the best thermal stability as observed by the very low weight loss after exposure to 150°C for 30 min. NX-5285 is another good option for more economical formulations that can accept a darker color.

Image 2: Photos of each foam



REF 2 | **SPF 1** | **SPF 2** | **SPF 3** | **SPF 4** | **SPF 5** | **SPF 6** | **SPF 7** | **SPF 8**

NX-9001/NX-5285 provide similar reactivity to reference, while NX-9006/ LITE 9006 are slower.

NX-9001/NX-9006/ LITE 9006 can be used at 5% level to maintain or improve fire resistance.

NX-9001 provides the highest compression strength.

NX-9006 shows the best thermal stability.

NX-5285 is a lower cost, darker alternative.

CNSL Polyols help lower water absorption.

Table 13: CNSL Additives in Spray Foam Formulations

Components (parts)	REF 1	REF 2	SPF 1	SPF 2	SPF 3	SPF 4	SPF 5	SPF 6	SPF 7	SPF 8
Sucrose-based polyether (OH 360)	35	35	35	35	35	35	35	35	35	35
Aromatic polyester (OH 250)	25	0	0	0	0	0	0	0	0	0
Aromatic polyester (OH 315)	0	25	20	10	20	10	20	10	20	10
Petro-Mannich polyol (OH 444)	40	40	40	40	40	40	40	40	40	40
NX-9001	0	0	5	15	0	0	0	0	0	0
NX-9006	0	0	0	0	5	15	0	0	0	0
NX-5285	0	0	0	0	0	0	5	15	0	0
LITE 9006	0	0	0	0	0	0	0	0	5	15
TCPP	15	15	15	15	15	15	15	15	15	15
Water	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
DABCO T12 (tin catalyst)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DABCO 33LV (amine catalyst)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
DABCO DC193 (silicone surfactant)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Cyclopentane	10	10	10	10	10	10	10	10	10	10
pMDI Index	115	115	115	115	115	115	115	115	115	115
Mix time (sec)	9	9	9	9	9	9	9	9	9	9
String time (sec)	18	17	18	19	19	22	16.5	17.5	18	20.5
Tack free time (sec)	22	20	20	22	23	25.5	21	20.5	22.5	25.5
Density (Kg/m³)	31.3	31	30.2	31.9	30.3	31.5	31.1	31.9	30.7	33.5
Compression strength, parallel (kPa)	141.8	123.7	133.7	128.5	121.7	128.8	117.1	122.8	117.4	124.4
Compression strength, perpendicular (kPa)	158.2	158.6	149.5	148.9	131.8	131.6	151.1	123.1	140.5	134.3
Tg (°C, DSC)	121.14	128.1	130.3	134.1	127.7	135	128.3	125.6	136.7	143.7
Weight loss (%, 30’ @ 150 °C)	2.24	1.65	1.54	1.69	1.19	1.1	1.26	2.78	2.61	3.43
Water absorption (%, 5 days)	0.65	0.37	0.05	0.1	0.15	0.19	0.35	0.23	0.22	0.01
Vertical UL-94 (afterflame, sec)	4.8	3.7	3.4	4.1	3.8	3.8	4.3	4.7	2.2	4.3

CNSL-BASED POLYOLS AS REPLACEMENTS FOR POLYESTER POLYOLS IN PIR FOAMS

PIR Boardstock and Panels

Table 14 shows the performance of PIR boardstock and panel formulations where the polyester polyols are fully or partially replaced with NX-9104.

Formulations J and K use Solstice LBA and water as the blowing agents. The full replacement of an aromatic polyester with NX-9104, results in a faster cure profile even with the use of less amine catalyst, similar density and slightly higher compression strength. The aromatic polyester offered higher LOI, but NX-9104 gave similar thermal conductivity and slightly better TGA results.

Formulation M illustrates the effect of partially replacing both aromatic and aliphatic polyesters with NX-9104 in comparison to Formulation L when pentane is used as blowing agent in combination with water. Mechanical, thermal and fire properties were comparable for both PIR foams, with the NX-9104-based foam providing slightly faster reaction times.

Table 14: PIR Boardstock and Panels Formulations with NX-9104

<table>
<tr><th colspan="2">Components (parts)</th><th>Formulation J</th><th>Fomulation K</th><th>Formulation L</th><th>Formulation M</th></tr>
<tr><td colspan="2">Polyether polyol (OH 360)</td><td colspan="2">30</td><td></td><td></td></tr>
<tr><td colspan="2">Aromatic -PA polyester polyol (OH 240)</td><td>70</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">NX-9104</td><td></td><td>70</td><td></td><td>20</td></tr>
<tr><td colspan="2">Aromatic -PET polyester polyol (OH 240)</td><td></td><td></td><td>50</td><td>40</td></tr>
<tr><td colspan="2">Aliphatic polyester polyol (OH 350)</td><td></td><td></td><td>50</td><td>40</td></tr>
<tr><td colspan="2">TCPP</td><td colspan="2">15</td><td colspan="2">20</td></tr>
<tr><td colspan="2">Silicone DC5598</td><td colspan="2">1.4</td><td colspan="2">2.5</td></tr>
<tr><td colspan="2">Dabco EM400</td><td></td><td></td><td></td><td>3</td></tr>
<tr><td colspan="2">Water</td><td>1.2</td><td>1.01</td><td colspan="2">0.7</td></tr>
<tr><td colspan="2">Dabco TMR2</td><td colspan="2">1.2</td><td></td><td></td></tr>
<tr><td colspan="2">Dabco K15</td><td colspan="2">1.5</td><td></td><td></td></tr>
<tr><td colspan="2">PMDETA</td><td>0.5</td><td>0.4</td><td></td><td></td></tr>
<tr><td colspan="2">Cat. LB</td><td></td><td></td><td colspan="2">1.2</td></tr>
<tr><td colspan="2">Dabco K15</td><td></td><td></td><td colspan="2">1.5</td></tr>
<tr><td colspan="2">Solstice LBA</td><td colspan="2">20</td><td></td><td></td></tr>
<tr><td colspan="2">Pentane</td><td></td><td></td><td colspan="2">15</td></tr>
<tr><td colspan="2">NCO Index</td><td colspan="2">250</td><td colspan="2">222</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">Mix Time (sec)</td><td>8</td><td>8</td><td>15</td><td>15</td></tr>
<tr><td colspan="2">String Time (sec)</td><td>43</td><td>38</td><td>126</td><td>102</td></tr>
<tr><td colspan="2">Tack Free Time (sec)</td><td>95</td><td>70</td><td>185</td><td>156</td></tr>
<tr><td colspan="2">Density, lb/ft³ (kg/m³)</td><td>2.33 (37.4)</td><td>2.35 (37.7)</td><td>1.98 (31.7)</td><td>2.01 (32.2)</td></tr>
<tr><td colspan="2">Compression strength, psi (kPa)</td><td>40.9 (282)</td><td>42.6 (294)</td><td>22.5 (155)</td><td>21.2 (146)</td></tr>
<tr><td rowspan="2">Thermal conductivity (l), Btu in/ft² hour °F (mW/mK)</td><td>24 °C</td><td>0.155 (22.4)</td><td>0.159 (23.0)</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td>10 °C</td><td>0.146 (21.1)</td><td>0.15 (21.7)</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td colspan="2">Limiting Oxygen Index (%)</td><td>27.0</td><td>24.5</td><td>24.7</td><td>24.8</td></tr>
<tr><td colspan="2">Temperature at 20% weight loss (°C, TGA air flow, scan 25-600 °C)</td><td>315.5</td><td>319.7</td><td>312.2</td><td>311.5</td></tr>
</table>

CNSL POLYOLS AS REPLACEMENTS FOR EDA AND o-TDA BASED POLYOLS IN PUR FOR FLOORING APPLICATIONS

Table 15: CNSL-based Polyols Comparison to EDA and o-TDA-based Polyols in PUR

Components (parts)	REF 1A	PUR 1A	REF 2A	PUR 2A	PUR 3A	PUR 4A	PUR 5A
Sucrose-based polyether polyol (OH 490)	30	30	30	30	30	30	30
Alkoxylated EDA-based polyol (OH 450)	20	20	0	0	0	0	0
Alkoxylated-oTDA polyol (OH 400)	0	0	20	20	20	0	0
Glycerine-based polyether polyol (OH 156)	10	0	10	0	0	10	0
NX-9001	0	10	0	10	0	0	10
NX-9102	0	0	0	0	0	20	20
NX-5285	0	0	0	0	10	0	0
TCPP	20	20	20	20	20	20	20
DC193	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Water	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DMCHA	1.4	1.4	1.4	1.4	1.4	0.8	0.8
Polycat 9	1.4	1.4	1.4	1.4	1.4	0.8	0.8
Dabco T12	0.2	0.2	0.2	0.2	0.2	0.05	0.1
Solkane 365/227	15	15	15	15	15	15	15
pMDI Index	150	150	150	150	150	150	150
Mix time (sec)	5	5	5	5	8	5	5
String time (sec)	26	21	28	24	25	17	15
Tack free time (sec)	37	29	37	35	39	36	34
Density (kg/m³)	44.4	43.4	44.1	46.2	41.2	46.1	48.4
Compression strength, parallel (kPa)	200	188	207	239	209	212	234
Compression strength, perpendicular (kPa)	219	232	217	225	217	207	225
Vertical UL-94 (after flame, sec)	2.8	1.8	1.8	2.1	1.4	2	1.1

CNSL polyols provide good mechanical properties and faster reactivity than alkoxylated EDA and o-TDA polyols.

CNSL polyols provide better fire resistance than alkoxylated EDA polyol and o-TDA polyols (PUR 5).

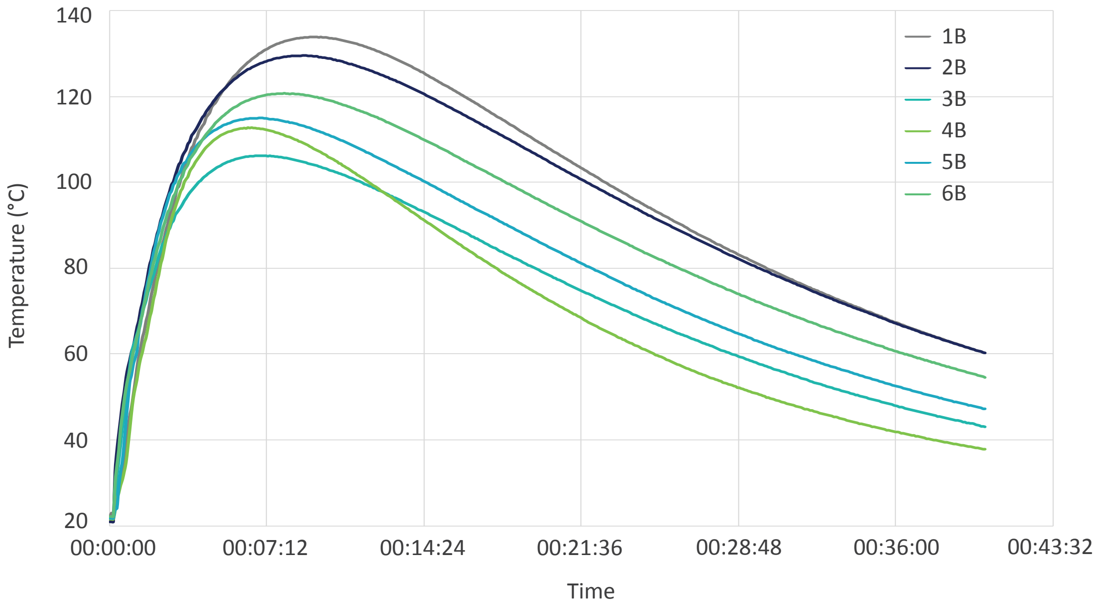
NX-9001 and NX-5285 are suitable replacements for glycerine polyether polyols (PUR 1/2/3) with adjustment in density.

CNSL POLYOLS PERFORMANCE IN PUR APPLIANCE FOAMS AS REPLACEMENTS FOR AROMATIC AMINE (o-TDA) INITIATED POLYOL

Table 16: CNSL Polyols Performance in PUR Appliance Foams

Components (parts)	REF (1B)	PUR 2B	PUR 3B	PUR 4B	PUR 5B	PUR 6B
Voranol RN490 (OH 490)	30	30	30	30	30	30
Voranol RN482 (OH 480)	20	20	20	20	20	20
Isoter 801SA (OH 300)	24	24	24	24	24	24
TD-405 (OH 400)	10	0	0	10	0	10
Elapol 80250 (OH 250)	4	4	4	0	4	0
NX-9102	0	10	7	0	7	0
NX-9001	0	0	3	0	0	0
NX-9104	0	0	0	4	0	0
NX-9006	0	0	0	0	3	0
NX-5285	0	0	0	0	0	4
DC193	1	1	1	1	1	1
DMCHA	1	1	1	1	1	1
Tegoamin A-33	1	1	1	1	1	1
Cyclopentane	9	9	9	9	9	9
pMDI Index	105	105	105	105	105	105
Mix time (sec)	10	10	10	10	10	10
String time (sec)	86	59	61	70	46	49
Tack free time (sec)	110	84	91	88	70	80
Density (kg/m³)	48.4	48.7	49.4	50.3	46.4	48.8
Exothermicity (°C)	133.8	129.5	106.2	112.7	120.8	129.9
Compression strength, parallel (kPa)	293	255	248	280	265	269
Compression strength, perpendicular (kPa)	261	253	259	270	233	255
Thermal conductivity (W/(m·K))	0.0257	0.0274	0.0253	0.0264	0.0295	0.0250

Graph 5: Exothermicity vs. time

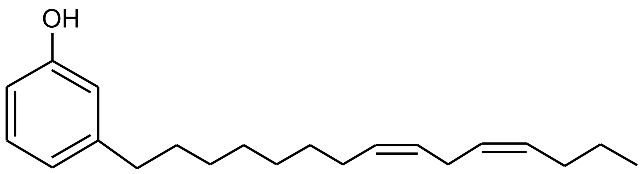


CNSL-based systems show faster reactivity, lower exothermicity and faster temperature release than reference, which allow shorter demolding time.

Formulas based on NX-9102/NX-9001 or NX-5285 show better thermal properties than reference.

DILUENTS FOR
POLYURETHANE FOAMS

Cardanol (average structure)



Mono-ethoxylated Cardanol (average structure)

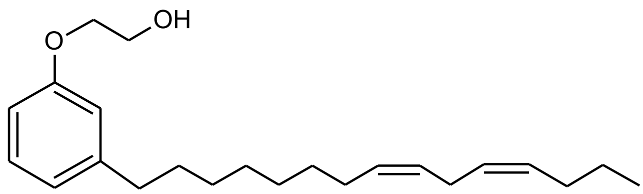


Table 17: Cardanol Typical Properties

Cardanol Grades	Color (Gardner)	Viscosity (cPs)
NX-2024	4 - 9	45 - 60
NX-2025	≤ 5	≤ 60
NX-2026[1]	≤ 2	≤ 60

[1] Average OH value (mg KOH/g) is 187

Table 18: Mono-ethoxylated Cardanol Typical Properties

Mono-ethoxylated Cardanol Grades[2]	Color (Gardner)	Viscosity (cPs)
LITE 2020[3]	≤ 14	30 -115
Ultra LITE 2020[3]	≤ 2	≤ 115

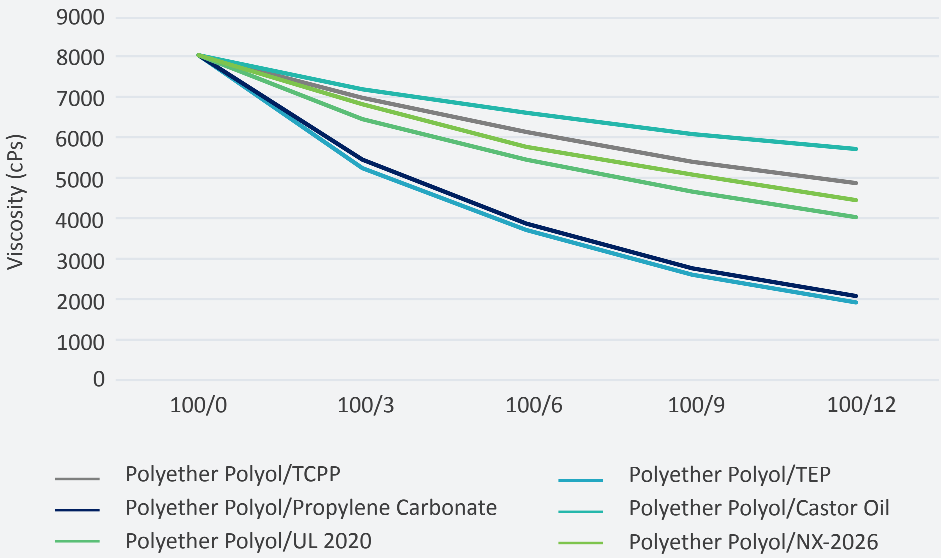
[2] LITE/UL 2020 are not European REACH registered.
[3] Average OH value (mg KOH/g) is 164

Benefits and Uses

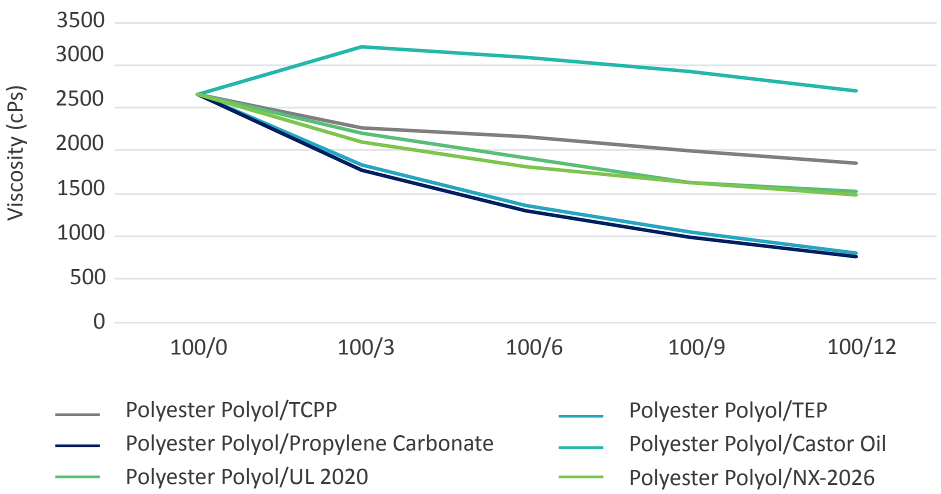
- Visco-reducer for PU foams
- Hydrophobic (less moisture sensitivity)
- Imparts flexibility
- Better fire resistance and thermal properties
- Alternative to castor oil and propylene carbonate
- Used at an approx. 5% level in the system (polyol/additives side)

VISCOSITY CURVE FOR
POLYURETHANES DILUENTS + POLYOLS

Graph 6: Dilution Power with Polyether Polyol



Graph 7: Dilution with Polyester Polyol



UL 2020 and NX-2026 showed good dilution power; better than TCPP and castor oil, but lower than TEP and propylene carbonate. All blends of additives with polyols were clear, except for ones based on castor oil and polyester polyol where haziness followed by phase separation was observed.

DILUENTS PERFORMANCE IN POLYURETHANE SPRAY FOAMS

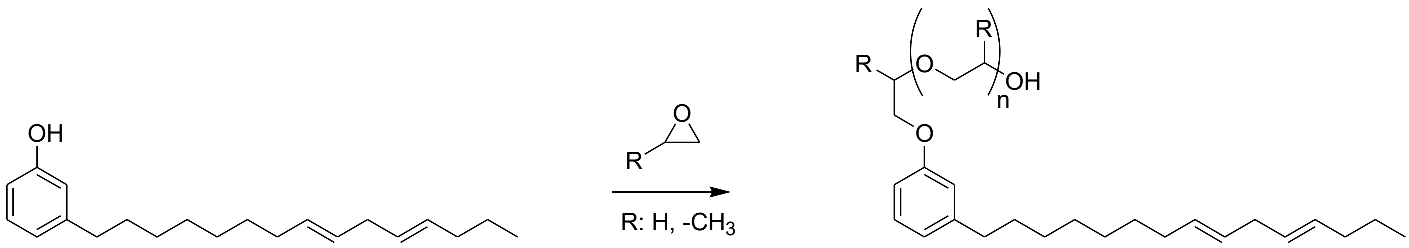
Table 19: Diluents Performance in Polyurethane Spray Foams

Components (parts)	REF 3	SPF 9	SPF 10	SPF 11	SPF 12	SPF 13	SPF 14
Sucrose-based polyether (OH 360)	35	35	35	35	35	35	35
Aromatic polyester polyol (OH 250)	25	25	25	25	25	25	25
Petro-Mannich polyol (OH 444)	40	40	40	40	40	40	40
TCPP	0	5	0	0	0	0	0
TEP	0	0	5	0	0	0	0
Propylene carbonate	0	0	0	5	0	0	0
Castor oil	0	0	0	0	5	0	0
UL 2020	0	0	0	0	0	5	0
NX-2026	0	0	0	0	0	0	5
TCPP (flame retardant)	15	15	15	15	15	15	15
Water	1.9	1.9	1.9	1.9	1.9	1.9	1.9
DABCO T12 (tin catalyst)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DABCO 33LV (amine catalyst)	1.2	1.2	1.2	1.2	1.2	1.2	1.2
DABCO DC193 (silicone surfactant)	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Cyclopentane	10	10	10	10	10	10	10
pMDI Index	115	115	115	115	115	115	115
Mix time (sec)	9	9	9	9	9	9	9
String time (sec)	18	18.5	18	17	18	17	19
Tack free time (sec)	22	22	21	21	21	21	22
Part A viscosity at 25°C (cPs, no BA)	1823	1611	1171	1212	1673	1474	1493
Density (FRD, Kg/m³)	31.3	32.7	31.3	31.8	33.7	31.5	32.1
Compression strength, parallel (kPa)	141.8	134.4	130.5	115.9	127.7	140.3	144.3
Compression strength, perpendicular (kPa)	158.2	156.0	146.0	167.0	167.9	146.8	160.8
Tg (°C, DSC)	121.1	118.7	119.0	117.3	121.0	125.5	126.3
Weight loss (%, 30’ @ 150 °C)	2.24	3.43	3.1	4.61	3.13	1.88	2.88
Water absorption (%, 5 days)	0.65	0.14	0.23	0.20	0.21	0.38	0.09
Vertical UL-94 (after flame, sec)	4.8	3.3	2.9	4.2	3.8	4.3	4.6

- Resulting foams show similar light yellow color.
- No significant difference in FRD was observed.
- Systems showed good mechanical properties, thermal properties (Tg) and fire resistance.
- The use of cardanol reduced weight loss after water immersion compared to other diluents.

SURFACTANTS FOR POLYURETHANE FOAMS

Cardanol Alkoxylation (average structures)



R = H, n=0: Ultra or LITE 2020, 1 EO cardanol (diluent)
R = H, n=6: NX-7507, 7 EO cardanol
R = H, n=8: NX-7509, 9 EO cardanol
R = H, n=11: NX-7512, 12 EO cardanol

Benefits and Uses

- Renewable cardanol ethoxylated surfactant
- Replacement for nonyl phenol ethoxylates and natural oil-based surfactants
- Partial replacement for silicone ethoxylates
- Non-toxic

CARDOLITE SURFACTANTS

Table 20: CNSL-based Surfactants

Properties	NX-7507 7 EO	NX-7509 9 EO	NX-7512 12 EO
Color (Gardner)	8	≤ 12	≤ 12
Viscosity at 25°C (cPs)	180	150 - 300	100 - 500
pH (5% Aq. Soln.)	8.1	7.0 - 10.0	6.5 - 9.0
HLB values (calculated)	10.1	11.4	12.8
OH value (mg KOH/g)	100	89	81
Cloud point (2% in BDG 10%)	66	74.5	80
Pour point (°C)	9	3	18
Surface tension (mN/m)	53.0	50.1	43.7
Foaming efficiency (ml at 0,1 wt.% actives, 25°C, initial/5 minutes)	24/23	28/27	47/42

Cardolite
Chemistry for Tomorrow

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