New Secondary Amine Chain Extenders for Aliphatic Polyurea Materials

Mark L. Posey, Kenneth M. Hillman and Howard P. Klein

Huntsman LLC, Austin Research Laboratories
7114 North Lamar Boulevard, Austin, Texas 78752, USA

ABSTRACT

Chain extenders are important components of polyurea formulations as they are needed to increase tensile strength and hardness. Huntsman has recently developed some new amine products that have shown promise as chain extenders in aliphatic and aromatic polyurea systems. The work reported in this paper will support their use in the preparation of aliphatic polyurea elastomers for coatings, adhesives and sealants.

Physical testing data has been collected on various aliphatic polyurea formulations using the new commercial product, JEFFLINK™ 754. These formulations will be compared to similar polyurea systems using standard chain extenders now known in the industry. Isophorone diisocyanate is used for all of the formulations reported herein, although the trends seen are believed general to all isocyanates. Most of the formulations were first tested in a double-barrel caulk gun and extruded through a static-mixing element. These coatings or castings were allowed to set up in a shallow metal mold so that they could easily be cut into physical testing specimens after a seven-day curing cycle at ambient temperature. The generation of coatings from the caulk gun allowed many different formulations to be tested in a short amount of time, with minimal use of raw materials. Several formulations were chosen for spray coating trials based upon preliminary data from the static-mix samples. Physical testing and results from the spray trials are presented as well.

It has been found that the biggest factor affecting coatings properties in aliphatic polyurea is the concentration of chain extender on the resin side. Cycloaliphatic chain extenders, when formulated to equal weight percent, should produce coatings with similar elongation, tensile strength, tear strength and hardness. Variations in system reactivity can be gained by adding alkyl groups to the primary nitrogens and/or changing the amount of physical blocking around the amine groups.

INTRODUCTION

In polyurea coatings there are two distinct types of formulation, aromatic and aliphatic. Aliphatic coatings are chosen when the end use requires the coating to be stable to ultraviolet light exposure. Early work with aliphatic systems utilized low molecular weight JEFFAMINE™ polyetheramines as the chain extenders. That work produced color stable systems, however the polyetheramines are considered "soft block" components. The resulting coatings were very flexible, but also soft and weak. Isophorone diamine has also been tried as a chain extender. It adds strength and hardness, however its high reactivity makes it difficult to obtain a smooth coating when sprayed.

UOP introduced the CLEARLINK® 1000 (CL1000) diamine, and this solved many of the problems holding back successful commercialization of aliphatic polyurea coatings. CL1000 is a secondary cycloaliphatic diamine which has blocking groups attached to the nitrogen. This provides for a slower reaction than with primary amines resulting in longer gel times that allow a smooth coating to form. Figure 1 gives the structures for JEFFLINK™ 754 AND CLEARLINK® 1000.

Prepared for presentation at the Polyurea Development Association 2003 Annual Conference, John Ascuaga's Nugget Casino Resort, Reno, NV, August 19-21, 2003.

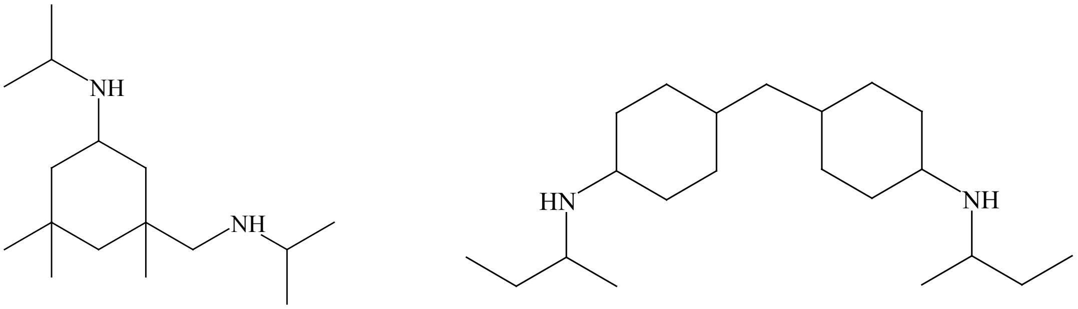

Figure 1. Structure diagrams for JEFFLINK™ 754 and CLEARLINK® 1000, respectively.

Huntsman has been working on its own chain extenders for many years. They originally came out with an experimental product named XTA-110. This is also a secondary chain extender based upon isophorone diamine. However, conversion to secondary amine was low (40-80%) resulting in difficulty with formulation. More recently, a breakthrough in catalyst technology has allowed very high conversion of the primary amine to secondary amine with very little tertiary amine formation. This breakthrough allowed the development of the current product, JEFFLINK™ 754 (JL754) shown in figure 1. Huntsman has now fully commercialized the process and production is proceeding from their chemical plant in Conroe, Texas. Table 1 below provides basic chemical data for the two chain extenders. Data for CL1000 came from the UOP Technical Bulletin[1].

Table 1. Comparison of basic chemical data for secondary aliphatic chain extenders

Compound	Molecular	Equivalent Weight	Density (25°C)	Viscosity (25°C)
	Weight	meq/gram	Grams/cc	cP
JEFFLINK™ 754	254	7.87	0.855	13
CLEARLINK® 1000	322	6.21	0.89	~ 100

Perez et. al[2]. presented a thorough paper on aliphatic formulations using CL1000 at the UTECH 2000 conference. They showed a strong dependence of coating physical properties with chain extender concentration as this work has also found. They showed a dramatic drop-off in properties at a CL1000 concentration below 31 wt% in the resin blend. This is not entirely accurate as their formulation at 31% also included 7.7 wt% isophorone diamine, which is also a chain extender that lends hardness and strength to the coating. If CL1000 was used alone, it is believed that properties would have dropped off around 35 wt%.

Given the prevalence of CL1000 formulations in the market, it makes sense to directly compare CL1000 performance with JL754. This paper should assist formulators and end-users in evaluating the two chain extenders side by side. Most of the data reported in the Perez paper used a 45 wt% IPDI/D-2000 prepolymer. Our work will also report 50 wt% prepolymers that require much more chain extender in the formulation. This allows comparison of the two chain extenders over a wider range of conditions.

Huntsman's Austin Research Labs has both static mix and high-pressure spray equipment. Both methods of coating formation were utilized and reported in this work. IPDI based aliphatic coatings had sufficient gel times at room temperature to achieve smooth and well mixed coatings using static mix equipment. This allowed us to evaluate many formulation alternatives while using minimal raw materials. The choice of the appropriate systems to spray was then made based upon these preliminary data.

EXPERIMENTAL

Chemicals

All chemicals used in this work were supplied from actual commercial inventories whenever possible. Table 2 lists all of the raw materials and their suppliers.

Prepolymers of IPDI and JEFFAMINE™ D-2000 were manufactured in the laboratory, five gallons at a time as they were needed. IPDI was first measured by weight into a five gallon can and mechanical stirring was begun under a nitrogen blanket. The required amount of D-2000 was then added slowly to the five gallon can by dripping it into the vortex created by the mixer. Slow addition of the D-2000 over several hours helps prevent high molecular weight pre-polymers from forming. All of the IPDI/D-2000 prepolymers in this work are quasi-prepolymers because each will have a significant amount of unreacted IPDI remaining.

Amine blends were made up by weight. The polyetheramines and any pigment were combined first. The pigment was dispersed in the polyetheramine using a Ross high-shear mixer Model ME 100L. High-shear mixing generates a lot of heat which can speed the discoloration of some chain extenders. Therefore, the chain extender is added last and the entire lot is mixed further using a power drill with a mixing blade. By adding the chain extender last this color formation is hopefully reduced.

Methods

There are two different methods of producing polyurea polymers utilized in this work. The first uses low-pressure equipment where mixing of the resin and isocyanate are accomplished using caulk tubes connected to a static mixing element. The second method uses plural component spray equipment with high-pressure, impingement mixing. Both techniques have been used in this work and results will be presented for both types of coating methods.

Static-Mix Materials and Methods

Coatings manufactured using low-pressure equipment will be referred to as "Static Mix" in this paper. Even though caulk guns and double-barrel caulk tubes are used, coating formulations processed in this manner are not necessarily suited for actual caulking applications.

Coating Formation

For all of the static-mix data reported, a pneumatically driven, double barrel caulk gun was used. Cartridge volumes were 200 mL for each side. Several different lengths and diameters of static mix tubes have been used. It was found that the 1/4" diameter tubes produced the best mixing compared to the 3/8" and 1/2" diameter static mixing elements. Unfortunately, the 1/4" tube significantly restricts the product flow and is not suitable for systems that are very fast at room temperature. In those cases, the 1/2" tube was used.

Coatings using the static mix technique were made by dispensing the polyurea into a shallow mold coated with mold release. Thickness of the coatings made in this manner averaged 0.15" (150 mils). After aging at least 7 days at room temperature, samples were die cut into physical testing specimens. Table 3 provides the ASTM methods followed for analysis of the coatings.

Because the polyurea coatings were dispensed into horizontal molds, gel time as typically defined, could not be measured. Instead, we report a "string gel" time. The surface of the freshly dispensed coating was touched repeatedly with a tongue depressor and string gel was declared when "peaks" of polymer were no longer formed. Tack free was defined as the time at which the surface was no longer sticky to a gloved finger.

Table 2. List of chemicals and suppliers

COMPOUND	MANUFACTURER	DESCRIPTION
JEFFAMINE® D-400 JEFFAMINE® D-2000 JEFFAMINE® T-5000	HUNTSMAN LLC	Polyetheramine
TIOXIDE® TiO_2	HUNTSMAN TIOXIDE	Titanium dioxide
JEFFLINK® 754	HUNTSMAN LLC	Secondary Aliphatic Amine Chain Extender
CLEARLINK® 1000	UOP	Secondary Aliphatic Amine Chain Extender
VESTANAT® IPDI	CREANOVA	Isophorone Diisocyanate

Table 3. ASTM test methods used in this study.

ASTM TEST METHOD			
Tensile Strength	ASTM D638 - Type IV	Hardness	ASTM D2240-81
Percent Elongation	ASTM D638 - Type IV	Taber Abrasion - H18 wheel	ASTM D4060
Modulus	ASTM D638 - Type IV	Gloss	ASTM D523
Tear Strength	ASTM D624 - Die C		

Spray Work

All of the spray data generated for this paper was sprayed using a Gusmer "The Marksman" proportioning system. Isocyanate and resin were provided to the Gusmer unit from small drum pumps in nitrogen padded five gallon pails. Preheaters and the hose heat were set to 160°F. Nozzle pressures were at or above 2000 psig. A Gusmer GX-7 Series 400 spray gun with a 212 PCD and a 453 mixing module was used.

Samples for testing were generated by spraying onto a horizontal plate that was coated with mold release. Sample thicknesses were 30 - 100 mils. Because the formulations in this report were purposely kept simple, they may not be ideal for commercial applications. The IPDI prepolymers have very high viscosities compared to the resin blend which results in pressure differences between the A and B side when sprayed. This may result in a coating that has a slightly different ratio than the formulation would indicate. These problems can be alleviated to some degree by adding thickening agents to the amine or thinning agents such as propylene carbonate to the isocyanate. We did not do either as it would complicate our comparisons.

RESULTS AND DISCUSSION

Static Mix Work

IPDI based aliphatic coatings are slow enough that good coatings can be formed using static mix equipment at room temperature. Using static mix equipment allows a researcher to quickly investigate many different formulations while utilizing very little raw material. For some isocyanates, especially those of NCO content above 16%, even at room temperature the formulation will gel too fast to achieve a good coating. All of the systems presented here were sufficiently slow so that a well mixed coating was achieved.

Table 4 gives the data for static mix systems with the IPDI/D-2000 prepolymer where IPDI was 45 wt% and D-2000 was 55 wt%. Note that this system is actually a quasi-prepolymer because much of the IPDI will remain unreacted. Three formulations are shown in Table 4. Two of them utilize JEFFLINK™ 754 and one uses CLEARLINK® 1000. We had wanted to form a coating at the 1.10 index with CL1000 for comparisons but depleted our raw material and could not obtain more before the submission deadline for this paper. For sample 8276-63-2, the isocyanate index was increased from 1.06 to 1.10 to see the effect on gel times and physical properties.

The key difference in the formulations is the chain extender concentration. Because of the lower equivalent weight of JL 754, not as much chain extender is required to meet the desired isocyanate index. On the face of it, this appears to be an advantage, as the formulator can achieve the desired result with much less chain extender which is the most expensive part of the formulation. However, we have found that the coating properties are very strongly tied to the chain extender concentration. Therefore, coating 8276-47 shows a higher elongation, but lower modulus at 100% and 300% than 8276-48. Tear strength is also significantly decreased when chain extender concentration is reduced. It is interesting to note that at the 1.06 index, the string gel and tack free times are essentially the same for JL754 and CL1000.

Table 4. Polyurea static-mix formulations with IPDI 45 wt% Quasi Prepolymer

IPDI/D-2000	**8276-47**	**8276-48**	**8276-63-2**
45 / 55 wt% Prepolymer % NCO	14.72	14.72	14.72
Resin Blend			
JEFFAMINE® D-2000	48.4	36.9	50.4
JEFFAMINE® T-5000	8.6	8.6	8.6
JEFFLINK® 754	36.0	0.0	34.0
CLEARLINK® 1000	0.0	47.5	0.0
TiO_2	7.0	7.0	7.0
Processing			
Index	1.062	1.062	1.104
Iso/Resin Volume Ratio	1.0	1.0	1.0
Iso/Resin Weight Ratio	1.021	1.021	1.018
Physical Property			
String Gel Time (sec)	42	47	32
Tack-Free Time (sec)	67	73	72
Hardness (0 sec)	52	61	46
(10 sec)	41	50	33
Tensile Strength (psi)	2700	2855	1997
Elongation (%)	1090	778	953
Modulus (100%) (psi)	770	1159	647
Modulus (300%) (psi)	952	1386	837
Tear Strength (pli)	405	601	385
Coating Density (g/cc)	1.031	1.045	0.983

Table 5 provides static mix data using a 50 wt% IPDI prepolymer. The higher NCO content compared to 45% provides for much harder and stronger coatings. Again, JL754 is compared with CL1000. For these data, the 16.8% NCO requires a much higher amine content, and thereby chain extender content on the B side. With JL754, chain extender concentrations around 45 wt% work well, while use of CL1000 requires 58 wt%. Formulations with very high chain extender content result in coatings that are very hard, but very brittle, not to mention very expensive. The hardness for the CL1000 formulation is probably a bit under reported because the sample cracked under the force of the Durometer needle resulting in a lower hardness value. We were not able to die cut testing specimens from the CL1000 formulation because the sample blank would crack and splinter under the force of the die. Therefore, no data can be presented for this formulation in static mix samples. We were able to get a spray sample of this formulation and that data is presented later in this paper.

Notice that the two formulations with JL754 gave very good properties. Both had high tensile strength, good flexibility and high tear strength. Therefore, at NCO contents above 16%, it would appear that the lower equivalent weight of JL754 is an advantage over CL1000. At this 50/50 isocyanate blend, JL754 appears to react faster than formulations with CL1000.

Table 5. Polyurea static-mix formulations with IPDI 50 wt% Quasi Prepolymer

IPDI/D-2000	**8276-30**	**8276-66-2**	**8276-31**
50 / 50 wt% Prepolymer			
% NCO	16.82	16.82	16.82
Resin Blend			
JEFFAMINE® D-2000	39	42.8	25
JEFFAMINE® T-5000	10	8.6	10
JEFFLINK® 754	44	41.6	0
CLEARLINK® 1000	0	0	58
TiO_2	7	7	7
Processing			
Index	1.06	1.101	1.061
Iso/Resin Volume Ratio	1.0	1.0	1
Iso/Resin Weight Ratio	1.036	1.032	1.036
Physical Property			
String Gel Time (sec)	35	36	49
Tack-Free Time (sec)	64	57	75
Hardness (0 sec)	62	61	57
(10 sec)	53	50	45
Tensile Strength (psi)	2657	2246	Too
Elongation (%)	819	721	Brittle
Modulus (100%)	1229	1096	To get
Modulus (300%)	1335	1239	Data
Tear Strength (pli)	623	566	N/A
Coating Density (g/cc)	1.039	1.036	1.02

In order to fairly compare the two chain extenders, coatings properties at similar wt% chain extender on the B side need to be evaluated. Table 6 compares static mix formulations 8276-30 and 8276-48. It is quite a remarkable discovery to find that every coating property is the same within experimental error. Elongation for both is approximately 800% with ultimate tensile strengths around 2800 psi. Both have a Shore D hardness in the low 60s and tear strengths are both in the low 600 pli range. This confirms the need to slightly reformulate when comparing JL754 and CL1000 based coatings.

Table 6. Formulation results at similar chain extender concentrations by the static mix method.

IPDI/D-2000 Prepolymer	**8276-30**	**8276-48**
% NCO	16.82	14.72
Resin Blend		
JEFFAMINE® D-2000	39	36.9
JEFFAMINE® T-5000	10	8.6
JEFFLINK® 754	44	0.0
CLEARLINK® 1000	0	47.5
TiO_2	7	7.0
Processing		
Index	1.06	1.062
Iso/Resin Volume Ratio	1.0	1.0
Iso/Resin Weight Ratio	1.036	1.021
Physical Property		
String Gel Time (sec)	35	47
Tack-Free Time (sec)	64	73
Hardness (0 sec)	62	61
(10 sec)	53	50
Tensile Strength (psi)	2657	2855
Elongation (%)	819	778
Modulus (100%)	1229	1159
Modulus (300%)	1335	1386
Tear Strength (pli)	623	601
Gloss 20 deg	60	63
60 deg	84	84
Coating Density (g/cc)	1.039	1.045

Spray Work Results

Conclusions drawn from the static-mix work lead us to test a series of spray formulations. These are essentially repeats of static-mix formulations to see if the trends were similar in sprayed systems. It should be noted that these formulations are not ideal for spraying. The IPDI prepolymers have a much higher viscosity than the resin blends. We did not compensate for this using thickening agents because it would complicate the data comparisons. The objective of this work was to compare the chain extenders at similar conditions rather than to do extensive work generating ideal spray formulations.

Table 7 provides the formulations and resulting coatings properties for the systems sprayed. The table is split into groups to aid in formulation comparison. The first pair compares JL754 with CL1000 at a 1.06 index and a 45/55 IPDI/D-2000 prepolymer. Note that JL754 concentration is only 36 wt% on the B side while CL1000 required 47.5 wt%. The two systems surprisingly had the same gel time of 10 seconds with the JL754 actually taking longer to reach tack free. As we found with the static-mix data, the system with the higher chain extender content provided a coating that was harder and stronger. Sample 8276-61 was harder and slightly stronger but had an elongation of 419% compared to 815% for 8276-62. The surface of 8276-62 seemed to take too long to cure resulting in a dull surface and poor gloss.

The second comparison pair in Table 7 increased the index to 1.10 to see the effect. The property trends were the same as the first pair, however at this index the CL1000 had a slightly longer gel time. Again, coating 8276-64-1 would be the better coating due to its 45 wt% chain extender content compared to 34 wt% in sample 8276-63-1.

The last three samples were sprayed with the 50/50 IPDI/D-2000 isocyanate. Chain extender content for JL754 is now in the range of 44 wt% while CL1000 requires 58 wt%. Recall from the static mix data that the CL1000 sample was too brittle to cut. For the spray data, perhaps because of the entrained air, sample 8276-60 was flexible enough, and thin enough, that physical properties could be measured. Sample 8276-60 showed the best abrasion resistance of all the samples tested due to its high chain extender content. All of the other samples can be considered equal in abrasion resistance within experimental error.

JL754 showed a faster cure than formulations with CL1000. All three made good coatings, with the higher chain extender content resulting in higher modulii at 100% and 300%. It is interesting that sample 8276-59 had a higher ultimate tensile strength than 8276-60, even though its 100% and 300% modulii are lower. This result can be explained by the higher elongation of 8276-59 at 875% compared to 493%. As the samples are pulled, more and more force is needed to continue pulling, so that similar samples with higher elongation will report higher ultimate tensile strengths. This raises a key question on the definition of a "stronger" coating. We recommend that polyurea specifiers compare all the physical property results and not just the ultimate tensile strength.

As was done for the static-mix data, comparisons at roughly equal chain extender concentrations are needed. In Table 7, a comparison of sample 8276-64-1 with 8276-66-1 is appropriate. Both samples have elongations around 700-800%, 100% modulus around 800 psi and 300% modulus around 1000 psi. Tear strengths for both are near 400 pli. Sample 8276-66-1 appears just a bit stronger at all conditions even though its chain extender content is only 41.6% compared to 45 wt% in 8276-64-1. Some of the increase in properties can be explained by the higher NCO content of 8276-66-1 at 16.8% compared to 14.7%

It was also interesting to note that all of the properties for the sprayed systems were less than equivalent formulations that were static-mixed. It was found that across the board, the coating densities for the sprayed systems were much lower than the static mix systems. It is hypothesized that the density difference is caused by entrained air in the sprayed samples. This in turn reduces the coating hardness and tensile properties somewhat. Therefore, results from static mix samples should be considered preliminary and for comparison purposes only.

Table 7. Polyurea spray formulation results.

IPDI/D-2000 Prepolymer	**8276-62**	**8276-61**	**8276-63-1**	**8276-64-1**	**8276-66-1**	**8276-59**	**8276-60**
% NCO	14.72	14.72	14.72	14.72	16.82	16.82	16.82
Resin Blend							
JEFFAMINE® D-2000	48.4	36.9	50.4	39.4	42.8	39	25
JEFFAMINE® T-5000	8.6	8.6	8.6	8.6	8.6	10	10
JEFFLINK® 754	36	0	34	0	41.6	44	0
CLEARLINK® 1000	0	47.5	0	45	0	0	58
TiO_2	7	7	7	7	7	7	7
Processing							
Index	1.062	1.062	1.104	1.101	1.101	1.06	1.061
Iso/Resin Volume Ratio	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Iso/Resin Weight Ratio	1.021	1.021	1.018	1.018	1.032	1.036	1.036
Physical Property							
Gel Time (sec)	10	10	11	14	7	5	8
Tack-Free Time (sec)	67	40	47	40	21	22	27
Hardness (0 sec)	40	51	40	51	58	55	65
(10 sec)	27	39	28	39	46	45	55
Tensile Strength (psi)	1186	1038	2157	1593	2236	2672	2121
Elongation (%)	815	419	1074	737	834	875	493
Modulus (100%)	518	786	561	757	889	1003	1434
Modulus (300%)	634	879	740	915	1047	1120	1550
Tear Strength (pli)	309	349	291	397	440	526	530
Abrasion (mg lost)	476	569	452	497	459	514	331
Gloss 20 deg	13.5	45.3	16.8	34.2	22.2	47.0	55.7
60 deg	44.5	79.9	54.7	70.7	62.7	83.0	85.3
Coating Density (g/cc)	0.849	0.821	0.931	0.834	0.866	0.919	0.884

CONCLUSIONS

Aliphatic polyurea coatings have been formed in order to compare the commercial chain extenders JEFFLINK™ 754 AND CLEARLINK® 1000. It has been found that a key parameter in the coating physical properties is the concentration of chain extender in the resin blend. Formulations with nearly the same weight percent cycloaliphatic chain extender had very similar physical properties. JEFFLINK™ 754 formulations showed slightly faster gel and tack free times, especially at high %NCO conditions. This work shows that the two chain extenders can be interchanged, however slight reformulation is necessary to maintain physical properties. CLEARLINK® 1000 will be favored at lower %NCO content while JEFFLINK™ 754 will have better cost and performance in high %NCO coatings.

ACKNOWLEDGMENTS

The authors would like to thank Richard Romerro and Ernie Villarreal for their assistance with the physical testing of the coating samples.

DISCLAIMER

Huntsman Corporation warrants only that its products meet the stated specifications. Typical properties, where stated, are to be considered as representative of current production and should not be treated as specifications. While all the information presented in this document is believed to be reliable and to represent the best available data on these products, NO GUARANTEE, WARRANTY, OR REPRESENTATION IS MADE, INTENDED, OR IMPLIED AS TO THE CORRECTNESS OR SUFFICIENCY OF ANY INFORMATION, OR AS TO THE SUITABILITY OF ANY CHEMICAL COMPOUNDS FOR ANY PARTICULAR USE, OR THAT ANY CHEMICAL COMPOUNDS OR USE THEREOF ARE NOT SUBJECT TO A CLAIM BY A THIRD PARTY FOR INFRINGEMENT OF ANY PATENT OR OTHER INTELLECTUAL PROPERTY RIGHT. EACH USER SHOULD CONDUCT A SUFFICIENT INVESTIGATION TO ESTABLISH THE SUITABILITY OF ANY PRODUCT FOR ITS INTENDED USE. Products may be toxic and require special precautions in handling. For all products listed, user should obtain detailed information on toxicity, together with proper shipping, handling, and storage procedures, and comply with all applicable safety and environmental standards.

References

1. "CLEARLINK™ 1000 DIAMINE", *UOP LLC Technical Bulletin, March 2000.*
2. Perez, A., Hillman, K.M., House, D.W., Scott, Jr., R.V., Ilijevski, D., " Secondary Aliphatic Diamine Chain Extenders in Aliphatic Polyurea Spray Applications", *UTECH 2000 Conference Paper,* The Hague, Netherlands.

BIOGRAPHY

Mark L. Posey

Mark Posey graduated from the University of Texas at Austin in 1992 with a B.S. and in 1996 with a Ph.D., both in Chemical Engineering. After two years with Phillips Petroleum R&D, Dr. Posey joined Huntsman's R&D group in Austin, Texas in the Process Technology Section. Mark worked on various assignments in process optimization and new process development supporting the Alkanolamines and Polyetheramines business units. His current position is Research Engineer with the Polyetheramines Applications Group, primarily focusing on polyurea technology. His key role is the technical development and testing of new molecules to support the polyurea industry.

Kenneth M. Hillman

Ken joined Jefferson Chemical Company (later Huntsman Corporation) in 1976, working in the Process and Development Group. After almost a decade of involvement in the manufacture of polyols and polyamines, Ken transferred to the Urethane Group/Performance Polymers Section in 1984, where Ken was responsible for the first demonstration/ application of spray-applied polyurea elastomers. Ken now holds the position of Senior Technical Specialist at Huntsman Corporation's Austin Laboratories where he continues to be involved in polyurea technology development.

Howard P. Klein

Howard P. Klein is a native of Cairo, Illinois. He received his B. S. degree in chemistry from the University of Illinois at Urbana in 1964 and a Ph.D. in organic chemistry from the University of Arizona at Tucson in 1967. Since then, Dr. Klein has been employed in Texas by the Jefferson Chemical Company, Texaco Chemical Company and Huntsman Corporation up to the current time. His research and development assignments have involved work on polyethylene oxide, polyamides, polyether polyols for polyurethane applications, amine-terminated polyethers and specialty amines for epoxy curing. He is the author of over 40 patents and several research papers. Dr. Klein's experience also includes the commercial development, marketing and sales of performance chemicals. He is now an Associate Fellow at the Huntsman Austin Laboratories, working in the area of commercial development for various performance chemicals, including polyetheramines and cyclic organic carbonates.

Prepared for presentation at the Polyurea Development Association 2003 Annual Conference,
John Ascuaga's Nugget Casino Resort, Reno, NV, August 19-21, 2003.