FLAME RETARDANT USAGE AND OTHER FACTORS AFFECTING BURN CHARACTERISTICS OF POLYURETHANE RIGID FOAMS

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BIOGRAPHICAL NOTE

David Modray received his BS in Chemical Engineering in 1995 from the University of Missouri-Columbia. For 18 years he has been employed by FSI as a research chemist. He is currently assigned to new product development where he has developed several commercially sold rigid foam systems. For the last 14 years he has been one of the primary formulators of ecomate® foam systems.

ABSTRACT

Flame retardants have historically been essential ingredients in polyurethane rigid foams, particularly where a specific fire rating is required. Over the years, flame retardant usage and availability has evolved to adapt to ever-changing environmental constraints and the type of fire rating required by the industry. The flame retardant package in a polyurethane foam will have a direct impact on its burn characteristics. The flame retardant selection and the amount used are critical to a good burn performance. Good burn characteristics are essential for polyurethane foams that require a fire rating such as foam used for building wall insulation. Like flame retardants, other ingredients in the resin blend affect the burn characteristics of polyurethane foam. This includes, but is not limited to, surfactants, catalysts, polyols, and blowing agents. Proper raw material selection and quantities used in a polyurethane foam formula are keys to an excellent burn performance.

In this paper, several ingredients in the resin blend of a polyurethane rigid foam will be evaluated. First, various flame retardants will be studied in polyurethane foams at three different isocyanate indexes. These foams will be evaluated for their burn characteristics with an in-house two-foot burn tunnel. This tunnel is equipped to measure flame distance and smoke evolved for an open flame burn with a constant air flow. Certain foams will also be analyzed via FTIR to determine proper cure. After an optimum flame retardant package has been selected, other ingredients, such as surfactant, catalyst, polyol, and blowing agent will be studied with the purpose of obtaining the optimum selection for burn characteristics.

INTRODUCTION

Insulation foam used for buildings must meet stringent fire testing requirements. Typically this involves a test in which the foam is burned in a tunnel with a constant air flow. To meet the fire test standards, the burned foam must have a limited flame propagation referred to as "flame spread" and have a limited amount of smoke generated also called "smoke index". Any foam used for building insulation must pass certain "flame spread" and "smoke index" requirements before they can be used.

Flame retardants are often used to meet these fire ratings. The flame retardants work in such a way to reduce the burn rate of the foam and create a protective char layer that will protect the unburned foam from the fire.

Generally, there are three types of foams used for wall insulation. The first is a high index foam (>250) called boardstock. Foams with this high of an index are also called "polyisocyanurate" foams. Index is calculated by dividing the number of isocyanate groups that went into the reaction mixture by the number of hydroxyl groups and then multiplying the result by 100. For example if a polyurethane mixture had 600 isocyanate groups and 200 hydroxyl groups, the index would be 300. High index foams make use of a

“Trimer” catalyst, which helps 3 isocyanate groups react with each other to form a 6 membered ring. This is shown in Figure 1.

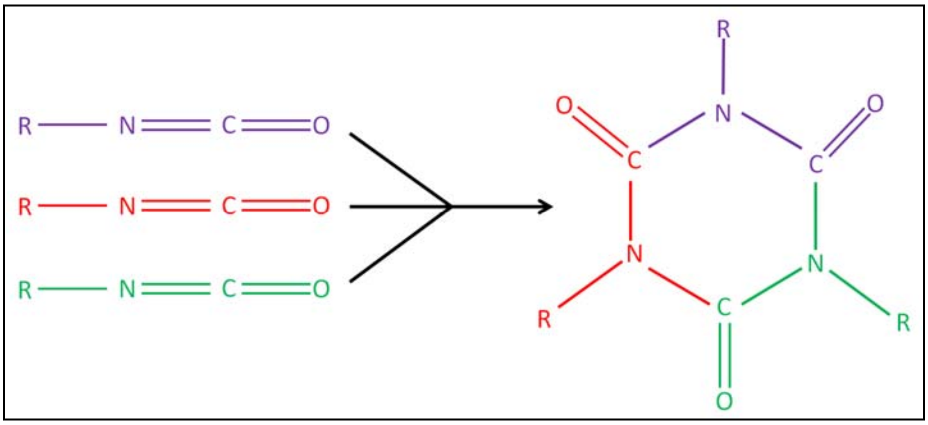

Figure 1 - Trimer Reaction

These Trimer rings are very rigid, giving the foam better dimensional stability. The Trimer rings are also very fire resistant, which imparts better burn characteristics to the foam. Formulators depend on this trimer formation when making higher index foams. If there is a problem with the trimer conversion in the polyurethane foam, this will result in reduced dimensional strength and poorer burn characteristics. A test to check trimer conversion is to test the foam in an FTIR scan. The trimer ring produces a strong, distinct peak in an FTIR scan and it will be larger when there are more trimer rings present. Below is a typical scan of a polyurethane boardstock formula with the trimer peak labeled.

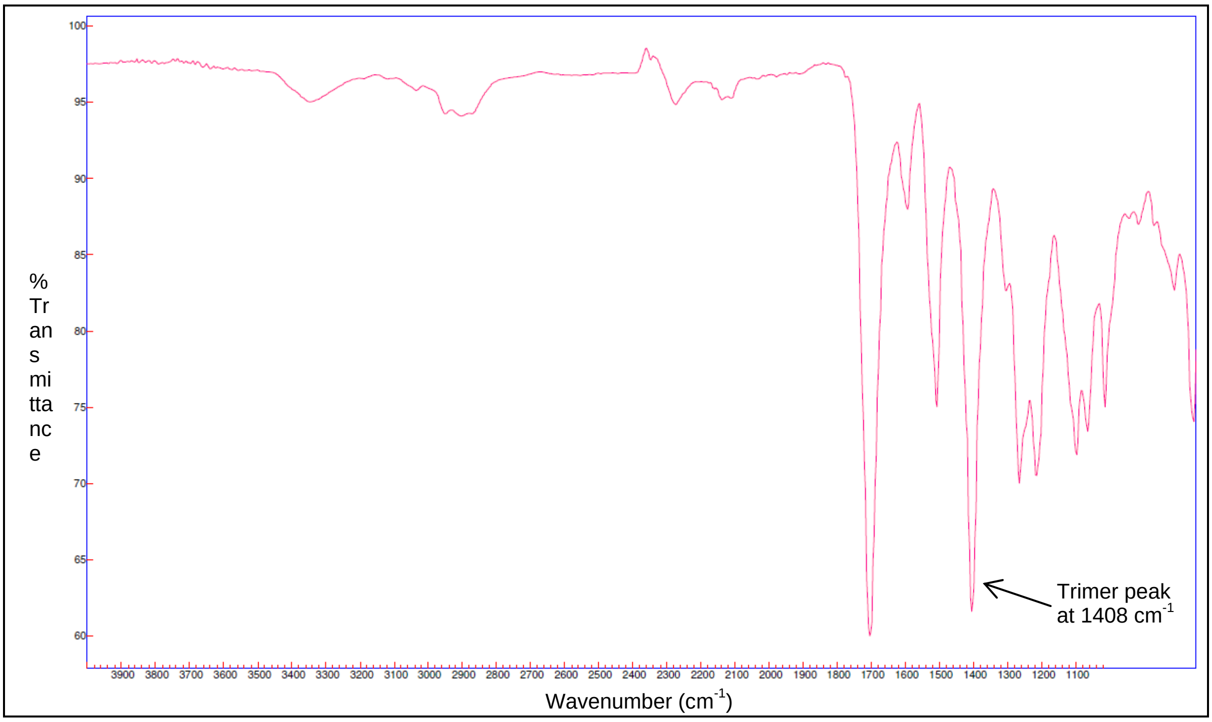

Figure 2 – FTIR Scan of a Boardstock Foam

In Figure 2, the large peak caused by the trimer rings can be seen at 1408 cm^{-1}.

The second type of foam used for wall insulation has a fairly high index (160-200), though not as high as a boardstock. This foam has a much slower reactivity, allowing it to be injected into a panel in a discontinuous process. This type of foam has some trimer content, but not as much as boardstock foams. For its fire rating, formulators generally need to use more flame retardants, and different types since some flame retardants will work better than others in this type of formula. Polyol selection also plays a more important role.

The third type of foam used for wall insulation has a low index (100-120). This type of foam relies heavily not only on the flame retardant selection, but also on many of the other ingredients. Formulators must select the proper and right amount of flame retardant, catalyst, surfactant, polyol and blowing agent in order to pass the burn test requirements.

The polyurethane formulator has many choices when selecting ingredients for a wall insulation foam. Several choices must be considered when making this type of formula. In the following experiments, I will look at all three type of foams discussed above, and try different flame retardants, catalysts, blowing agents, polyols, and surfactants, the goal being to try to find the ingredients that will give optimum burn characteristics.

EXPERIMENTAL

Each of the three types of foams, high index, medium index, and low index were evaluated separately since typical formulations vary greatly among the three types. To evaluate burn characteristics, an in-house small scale burn tunnel was used. This tunnel provides an accurate estimation of burn characteristics obtained from ASTM E-84, a standard test method for surface burning characteristics. A diagram of the small scale tunnel is given in Figure 3.

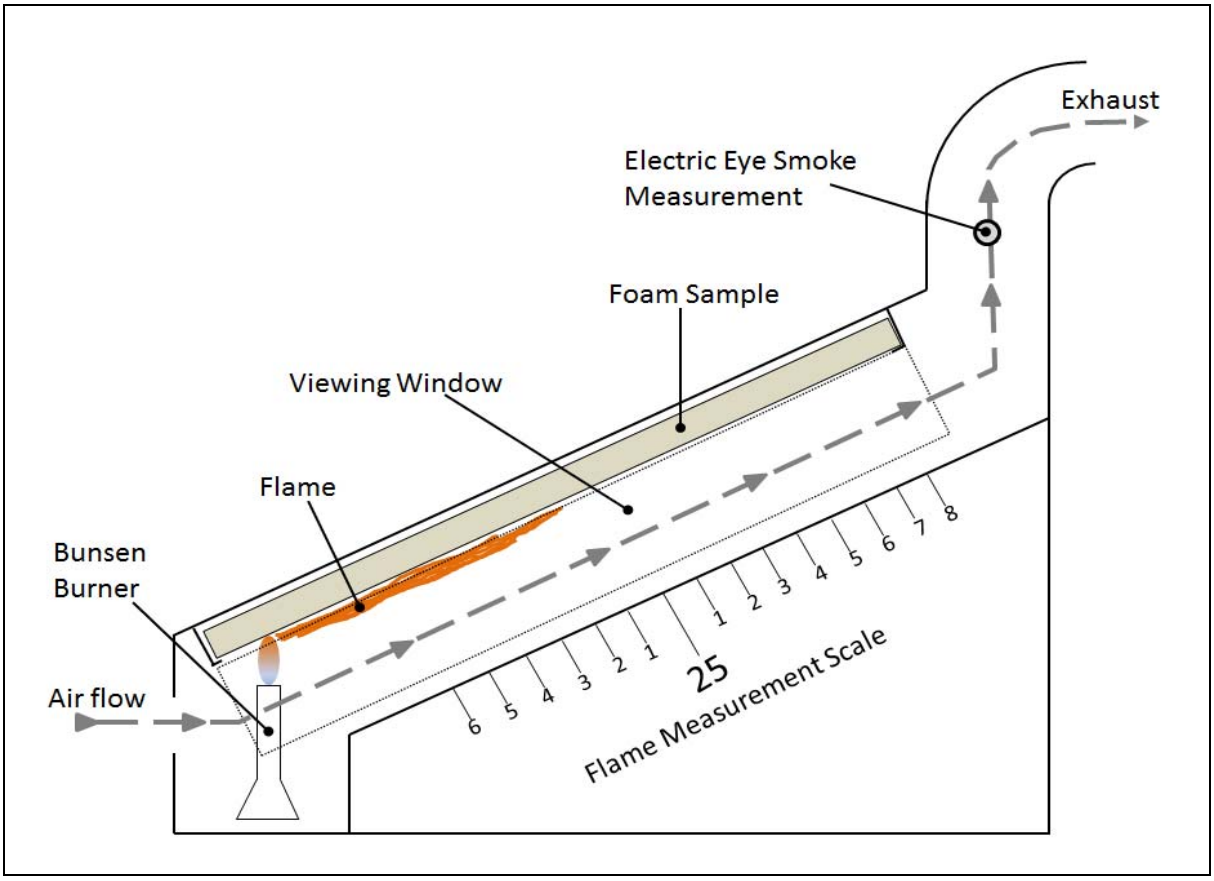

Figure 3 – Diagram of Small Scale Burn Tunnel

While a constant flow of air is pulled through the tunnel, a Bunsen burner is ignited on the underside of an angled foam sample. A flame will form on the surface of the foam, which will be viewable through the side window. The maximum flame distance is measured on an adjacent scale. There is a “25” located on the scale and flame measurements are recorded as either inches above or inches below the “25” mark. As the air flow exits the combustion chamber, it is pulled up through an electric eye that measures the amount of smoke evolved. The smoke value is a cumulative measurement of smoke given off of the burning foam over the course of 150 seconds. The electric eye sends a signal to a computer that calculates cumulative smoke values.

High Index Boardstock

The first formula evaluated was the high index formula. I started with formula 14B8, a high index formula for boardstock. The resin blend for this formula is shown in Table 1.

Table 1 – 14B8 Resin Blend

Chemical	%
Polyester Polyol 1	75.4
Tris (1-Chloro 2-propyl) Phosphate (TCPP)	10
Surfactant 1	1.5
Proprietary Additive A	0.35
Blowing Catalyst 1	0.3
Trimer Catalyst A	2.5
ecomate®	10.0

The resin blend was mixed with polymeric MDI at a ratio that gave a foam with an isocyanate index of 280. Several variations were made to this formula, each named according to a slight change made to the base formula. Table 2 shows each formula made and the variation associated with it.

Table 2 – 14B8 Formula Table

Formula Name	Variation from formula 14B8
Control	No change; same as it is written above
Flame Retardant A	The TCPP was replaced with Flame Retardant A
Flame Retardant B	The TCPP was replaced with Flame Retardant B
Half TCPP	The TCPP content was reduced from 10% to 5%
TEP	The 10% TCPP was replaced with 5% Triethyl Phosphate (TEP)
Pentane	The ecomate® was replaced with a molar equivalent of n-pentane
Methylal	The ecomate® was replaced with a molar equivalent of methylal
365mfc	The ecomate® was replaced with a molar equivalent of 365mfc
Surfactant 2	The Surfactant 1 was replaced with Surfactant 2
Surfactant 3	The Surfactant 1 was replaced with Surfactant 3
Polyester Polyol 3	The polyester polyol 1 was replaced with polyester polyol 3
Trimer Catalyst B	The Trimer Catalyst A was replaced with Trimer Catalyst B

Formula weight ratios were adjusted to maintain a 280 index when necessary. Samples were prepared by mixing foam on a high speed pneumatic mixer and then poured onto a plastic lined counter. After curing, the foam samples were cut to the proper dimensions for a small scale burn tunnel test. Each formula was burned in the small scale burn tunnel. The maximum flame length and smoke evolved were recorded. Calculations were then made to provide an estimation of the ASTM E-84 test. The calculations are based on the burning of a standard foam used to calibrate the tunnel. These results are in Table 3.

Table 3 – 14B8 Burn Results

Formula	Flame	Smoke	E-84 Flame*	E-84 Smoke*
Control	4”<25	1.1	15	35
Flame Retardant A	1”<25	6.7	22	220
Flame Retardant B	1”<25	8.5	22	280
Half TCPP	2”<25	0.8	20	25
TEP	4”<25	1.5	15	50
Pentane	1”<25	1.9	22	65
Methylal	2”<25	1.4	20	45
365mfc	3”<25	2.3	17	75
Surfactant 2	4”<25	1.0	15	35
Surfactant 3	4”<25	1.3	15	40
Polyester Polyol 3	2”<25	1.2	20	40
Trimer Catalyst B	3”<25	1.4	17	45

*Estimated Values

In order to understand which choice is optimum, each additive group will be analyzed individually. First, the flame retardant group will be analyzed. This group is in table 4.

Table 4 – 14B8 Burn Results Flame Retardants Only

Formula	E-84 Flame*	E-84 Smoke*
Control(TCPP)	15	35
Flame Retardant A	22	220
Flame Retardant B	22	280
Half TCPP	20	25
TEP	15	50

Flame Retardant A and Flame Retardant B are both brominated flame retardants with Flame Retardant B having some reactive hydroxyl groups. It appears that their use in the boardstock formula is unnecessary since both formulas increased in smoke and flame. Cutting the TCPP content in half appears to reduce smoke, but increase flame. Using TEP in place of the TCPP has the same flame, but higher smoke. The best flame retardant package in this formula is half TCPP since using half as much still yielded great burn characteristics.

The next set to examine is the blowing agents. This group is in table 5.

Table 5 – 14B8 Burn Results Blowing Agents Only

Formula	E-84 Flame*	E-84 Smoke*
Control(ecomate®)	15	35
Pentane	22	65
Methylal	20	45
365mfc	17	75

In this set, ecomate® is the best suited blowing agent for this formula since all others tried, pentane, methylal, and 365mfc, resulted in higher flame and smoke values.

The third set to analyze is the surfactant. Table 6 shows each formula and the surfactants tested.

Table 6 – 14B8 Burn Results Surfactant Only

Formula	E-84 Flame*	E-84 Smoke*
Control(Surfactant 1)	15	35
Surfactant 2	15	35
Surfactant 3	15	40

This set demonstrates that the surfactant selected for this formula has little to no effect on burn characteristics. There is not a significant difference in burn characteristics among the three surfactants tested in this study.

The next set examines the effect of a different polyester polyol used. Table 7 shows the burn results of the two polyester polyols tested.

Table 7 – 14B8 Burn Results Polyester Polyols Only

Formula	E-84 Flame*	E-84 Smoke*
Control(Polyester Polyol 1)	15	35
Polyester Polyol 3	20	40

In this set, there appears to be a slight advantage to using Polyester Polyol 1 over 3 since Polyester Polyol 1 had slightly better burn characteristics. It should be noted that there are many polyester polyols available that were not tested in this study.

The last set in this study looks at using a different catalyst for trimerization. The burn results are shown in Table 8.

Table 8 – 14B8 Burn Results Catalysts Only

Formula	E-84 Flame*	E-84 Smoke*
Control(Trimer Catalyst A)	15	35
Trimer Catalyst B	17	45

This table shows a slight advantage to using Trimer Catalyst A versus B since the burn characteristics of Trimer Catalyst B were slightly higher flame and smoke values.

Medium Index Discontinuous Panel Formula

The second formula evaluated was the medium index formula. I started with formula 14B9, a medium index formula for discontinuous panels. The resin blend of this formula is shown in Table 9.

Table 9 – 14B9 Resin Blend

Chemical	%
Sucrose-Glycerin Polyol 1	10
Polyester Polyol 1	52.5
TCPP	10
Flame Retardant A	14
Water	1.8
Surfactant 3	1.5
Blowing Catalyst 1	0.2
Trimer Catalyst A	1.5
Proprietary Additive A	0.5
ecomate®	8.0

The resin blend was mixed with polymeric MDI at a ratio that gave a foam with an isocyanate index of 200.

Several variations were made to this formula, each named according to a slight change made to the base formula. Table 10 shows each formula made and the variation associated with it.

Table 10 – Formula 14B9 Variation Table

Formula Name	Variation from 14B9
Control	No change; Same as it is written above
Half TCPP	The TCPP content was reduced from 10% to 5%
TEP	The 10% TCPP was replaced with 5% TEP
Flame Retardant B	Flame Retardant A was replaced with Flame Retardant B
Flame Retardant C	Flame Retardant A was replaced with Flame Retardant C
Flame Retardant D	Flame Retardant A was replaced with Flame Retardant D
Pentane	The ecomate® was replaced with a molar equivalent of n-pentane
Methylal	The ecomate® was replaced with a molar equivalent of methylal
365mfc	The ecomate® was replaced with a molar equivalent of 365mfc
Surfactant 1	The Surfactant 3 was replaced with Surfactant 1
Surfactant 2	The Surfactant 3 was replaced with Surfactant 2
Polyester Polyol 3	The Polyester Polyol 1 was replaced with Polyester Polyol 3
Trimer Catalyst B	The Trimer Catalyst A was replaced with Trimer Catalyst B

Formula weight ratios were adjusted to maintain a 200 index when necessary. Samples were prepared by mixing foam on a high speed pneumatic mixer and then pouring into a small mold that replicates foam packed in a discontinuous panel. After curing, the foam samples were cut to the proper dimensions for a small scale burn tunnel test. Each formula was burned in the small scale burn tunnel. The maximum flame length and smoke evolved were recorded. Calculations were then made to provide an estimation of the ASTM E-84 test. The calculations are based on the burning of a standard foam used to calibrate the tunnel. These burn test results are in Table 11.

Table 11 – 14B9 Burn Results

Sample	Flame	Smoke	E-84 Flame*	E-84 Smoke*
Control	2”<25	10.2	20	325
Half TCPP	1”<25	9.1	22	290
TEP	1”<25	11.7	22	370
Flame Retardant B	=25	24.8	25	785
Flame Retardant C	=25	16.7	25	530
Flame Retardant D	=25	25.9	25	820
Pentane	=25	13.0	25	410
Methylal	=25	11.3	25	360
365mfc	2”<25	10.9	20	345
Surfactant 1	2”<25	6.9	20	220
Surfactant 2	2”<25	9.2	20	290
Polyester Polyol 3	1”<25	9.2	22	290
Trimer Catalyst B	1”<25	17.1	22	540

*Estimated Values

In order to understand which choice is optimum, each additive group will be analyzed individually. First, the phosphorus flame retardant group will be analyzed. This group is in table 12.

Table 12 – 14B9 Burn Results Phosphorus Flame Retardants Only

Sample	E-84 Flame*	E-84 Smoke*
Control(TCPP)	20	325
Half TCPP	22	290
TEP	22	370

In this group, just like the boardstock formula, cutting the amount of TCPP in half reduced smoke, but increased flame. The TEP showed no advantage since its use in this formula increased both the flame and the smoke values. The Half TCPP again is the best in this formula.

In the second set, the brominated flame retardants will be analyzed. The burn results for this set are in Table 13.

Table 13 – 14B9 Burn Results Brominated Flame Retardants Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Flame Retardant A)	20	325
Flame Retardant B	25	785
Flame Retardant C	25	530
Flame Retardant D	25	820

In this group there is a clear advantage to using Flame Retardant A since the flame and smoke values were much lower than any of the others tried. It should be noted that Flame Retardant A has no reactive hydroxyl groups whereas Flame Retardants B, C, and D contain reactive hydroxyl groups. In an attempt to explain what happened in the foams with Flame Retardants B, C, and D, an FTIR was run on the cured foams from these samples. First, the Control with Flame Retardant A was analyzed. It produced the spectrum in Figure 4.

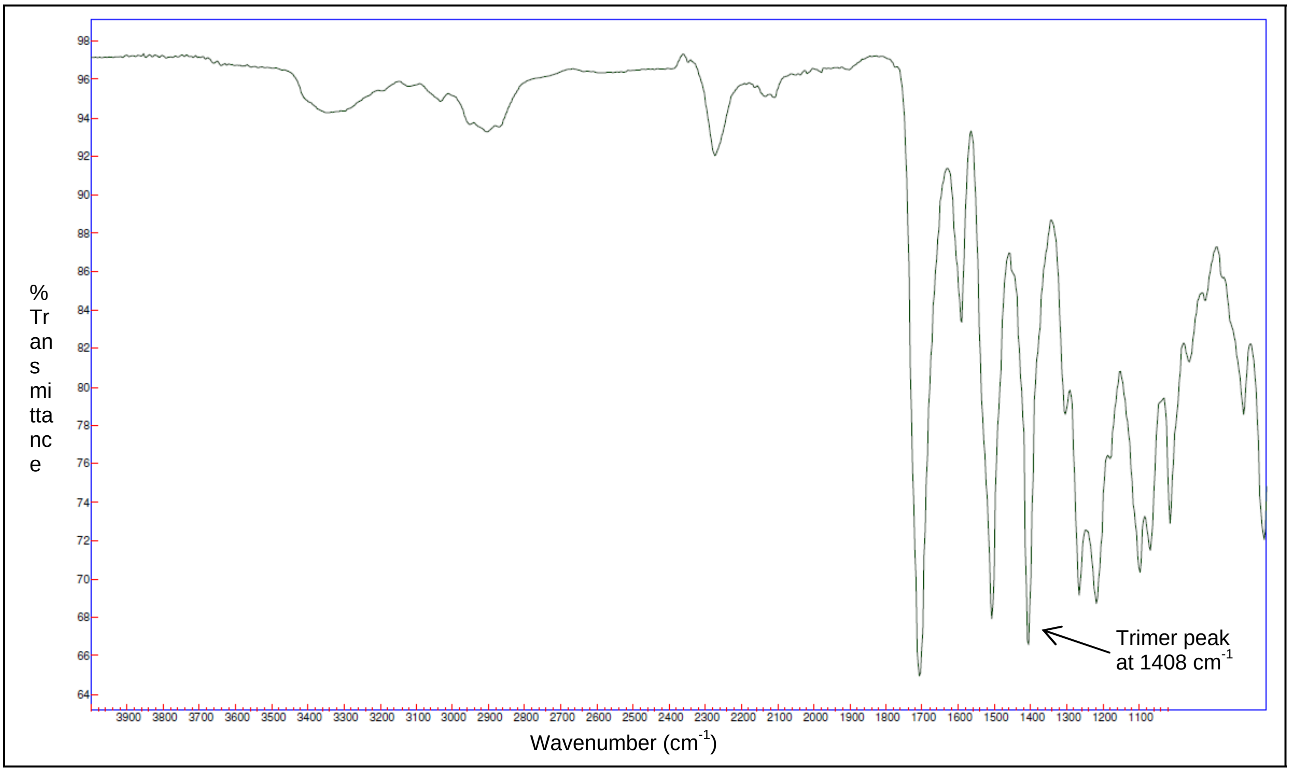

Figure 4 – FTIR Spectrum of Cured Foam of 14B9 Control (Flame Retardant A)

The spectrum of 14B9 with Flame Retardant A produced a strong trimer peak, showing a high formation of trimer rings. The second foam tested in FTIR was 14B9 with Flame Retardant B. This is shown in Figure 5.

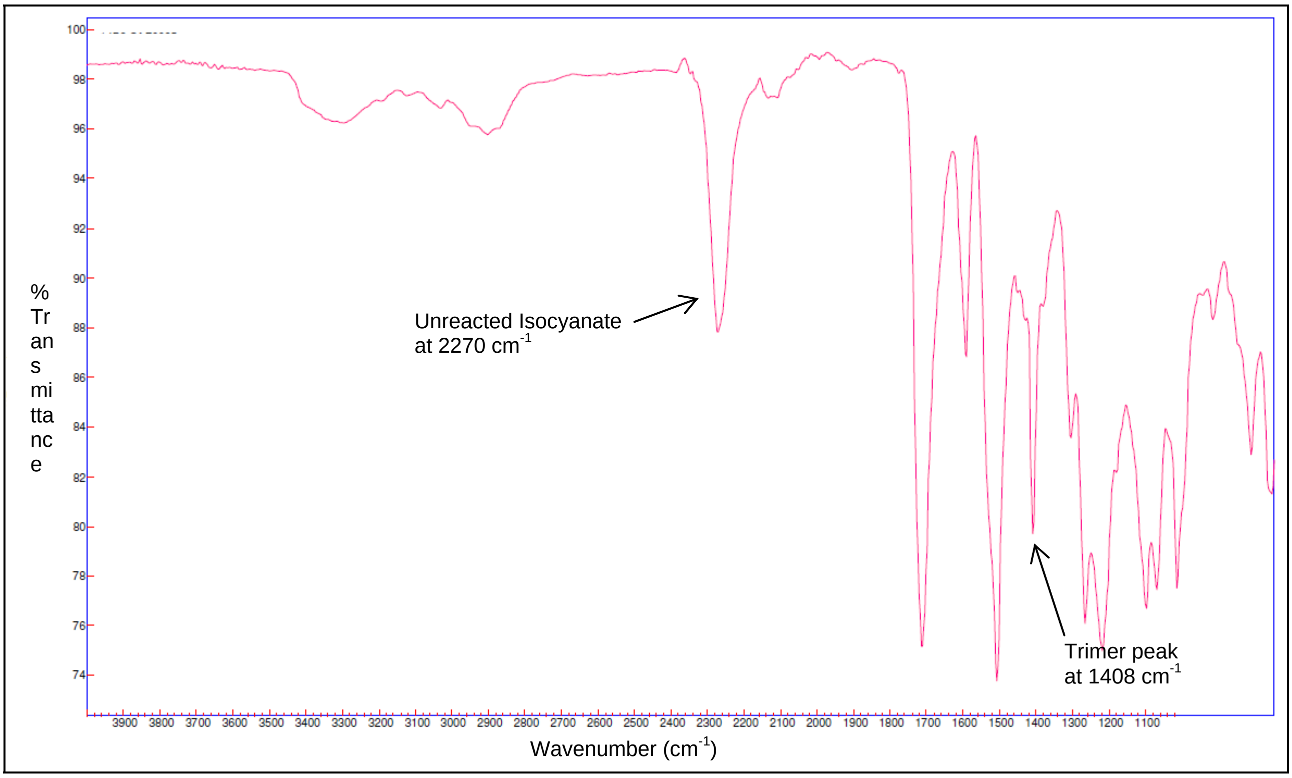

Figure 5 – FTIR Spectrum of Cured Foam of 14B9 Made with Flame Retardant B

The spectrum of 14B9 with Flame Retardant B produced a much smaller trimer peak, indicating that a much smaller amount of trimer rings are present in this foam. In addition, there is also a significant amount of unreacted isocyanate present as shown by the large peak at 2270 cm^{-1}. The trimer rings are necessary for good burn characteristics. This means that the reason for the poorer burn characteristics seen in 14B9 with

Flame Retardant B was that the foam formed fewer trimer rings during the foaming reaction. The same phenomenon can be seen in 14B9 made with Flame Retardant C. The FTIR spectrum is in Figure 6.

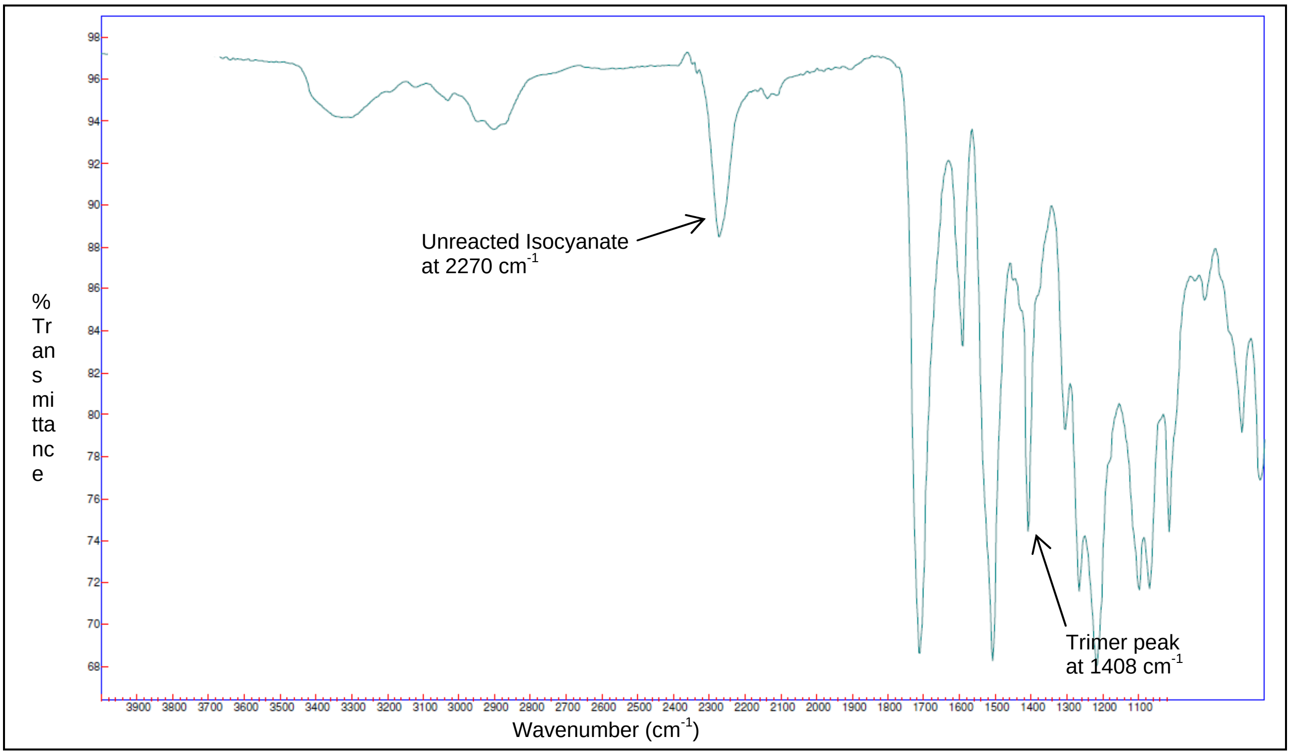

Figure 5 – FTIR Spectrum of Cured Foam of 14B9 Made with Flame Retardant C

Just like the 14B9 made with Flame Retardant B, this foam with Flame Retardant C shows the same loss in trimer formation versus the control. This group shows that of the brominated flame retardants, Flame Retardant A performed the best in terms of burn characteristics.

The third group of this formula to be examined is the blowing agents. Table 14 shows the burn test results.

Table 14 – 14B9 Burn Results Blowing Agent Only

Sample	E-84 Flame*	E-84 Smoke*
Control(ecomate®)	20	325
Pentane	25	410
Methylal	25	360
365mfc	20	345

In this set, ecomate® is the best suited blowing agent for this formula. The formulas with pentane and methylal had higher flame and smoke. The formula with 365mfc had about the same flame and smoke values, but more than twice as much of the 365mfc by weight had to be used to match the molar substitution with ecomate®. In this set, ecomate® is the best suited blowing agent for burn characteristics.

The next set to be evaluated is the surfactants. Table 15 shows the burn results.

Table 15 – 14B9 Burn Results Surfactants Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Surfactant 3)	20	325
Surfactant 1	20	220
Surfactant 2	20	290

In this set, all formulas had the same flame value, but Surfactant 1 shows a clear advantage with the lowest smoke. Surfactant 1 performed the best in this set.

The next set for analysis is the polyester polyols. The burn results are in Table 16.

Table 16 – Burn Results Polyester Polyols Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Polyester Polyol 1)	20	325
Polyester Polyol 3	22	290

This set shows that both polyester polyols performed about the same with only a small variance in flame and smoke values. As mentioned before, there are many different polyester polyols not tested in this set.

The last set in this series is the catalyst comparison. The results are in Table 17.

Table 17 – Burn Results Catalysts Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Trimer Catalyst A)	20	325
Trimer Catalyst B	22	540

This set show that Trimer Catalyst A gives better burn characteristics that Trimer Catalyst B since Trimer Catalyst A had lower flame and smoke values.

Low Index Discontinuous Panel Formula

The third formula evaluated was the low index formula. I started with formula 14B10, a low index formula for discontinuous panels. The resin blend of this formula is shown in Table 18.

Table 18 – 14B10 Resin Blend

Chemical	%
Sucrose-Glycerin Polyol 1	30
Polyester Polyol 2	46.9
Flame Retardant B	12
Surfactant 2	3.0
Water	3.0
Proprietary Additive A	0.5
Blowing Catalyst 2	0.6
Ecomate®	4.0

The resin blend was mixed with polymeric MDI at a ratio that gave a foam with an isocyanate index of 120.

Several variations were made to this formula, each named according to a slight change made to the base formula. Table 19 shows each formula made and the variation associated with it.

Table 19 – Formula 14B10 Variation Table

Formula Name	Variation from 14B10
Control	No change; Same as it is written above
Flame Retardant A	Flame Retardant B was replaced with Flame Retardant A
Flame Retardant C	Flame Retardant B was replaced with Flame Retardant C
Flame Retardant D	Flame Retardant B was replaced with Flame Retardant D
Pentane	The ecomate® was replaced with a molar equivalent of n-pentane
Methylal	The ecomate® was replaced with a molar equivalent of methylal
365mfc	The ecomate® was replaced with a molar equivalent of 365mfc
Surfactant 1	The Surfactant 2 was replaced with Surfactant 1
Surfactant 3	The Surfactant 2 was replaced with Surfactant 3
Polyester Polyol 1	The Polyester Polyol 2 was replaced with Polyester Polyol 1
Polyester Polyol 3	The Polyester Polyol 2 was replaced with Polyester Polyol 3
Polyester Polyol 4	The Polyester Polyol 2 was replaced with Polyester Polyol 4
Blowing Catalyst 1	The Blowing Catalyst 2 was replaced with Blowing Catalyst 1

Formula weight ratios were adjusted to maintain a 120 index when necessary. Samples were prepared by mixing foam on a high speed pneumatic mixer and then pouring into a small mold that replicates foam packed in a discontinuous panel. After curing, the foam samples were cut to the proper dimensions for a small scale burn tunnel test. Each formula was burned in the small scale burn tunnel. The maximum flame length and smoke evolved were recorded. Calculations were then made to provide an estimation of the

ASTM E-84 test. The calculations are based on the burning of a standard foam used to calibrate the tunnel. These results are in Table 20.

Table 20 – 14B10 Burn Results

Sample	Flame	Smoke	E-84 Flame*	E-84 Smoke*
Control	=25	12.3	25	360
Flame Retardant A	3”>25	20.9	32	615
Flame Retardant C	1”>25	10.0	27	295
Flame Retardant D	=25	13.3	25	390
Pentane	3”>25	15.5	32	455
Methylal	2”>25	12.8	30	375
365mfc	1”>25	21.2	27	625
Surfactant 1	5”>25	30.9	37	910
Surfactant 3	4”>25	35.8	35	1055
Polyester Polyol 1	2”>25	20.4	30	600
Polyester Polyol 3	2”>25	22.1	30	650
Polyester Polyol 4	2”>25	23.3	30	685
Blowing Catalyst 1	=25	13.2	25	390

*Estimated Values

In order to understand which choice is optimum, each additive group will be analyzed individually. First, the flame retardant group will be analyzed. This group is in table 21.

Table 21 – 14B10 Burn Results Flame Retardants Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Flame Retardant B)	25	360
Flame Retardant A	32	615
Flame Retardant C	27	295
Flame Retardant D	25	390

This set of flame retardants shows that Flame Retardants B, C, and D performed much better than Flame Retardant A. It should also be pointed out that Flame Retardants B, C, and D have reactive hydroxyl groups on them whereas Flame Retardant A does not. It appears that reactive brominated flame retardants work better in this type of formula than ones that are non-reactive. Flame Retardant B probably is the best choice in this formula.

The second set for evaluation is the blowing agents. The burn results are shown in Table 22.

Table 22 – 14B10 Burn Results Blowing Agents Only

Sample	E-84 Flame*	E-84 Smoke*
Control(ecomate®)	25	360
Pentane	32	455
Methylal	30	375
365mfc	27	625

In this set, the burn test results show that ecomate® is the best choice for burn characteristics in this set. It produced foams with the best burn characteristics of the ones tried in this formula with lower flame and smoke values.

The next set analyzed was the surfactant set. The burn results are in Table 23.

Table 23 – 14B10 Burn Results Surfactants Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Surfactant 2)	25	360
Surfactant 1	37	910
Surfactant 3	35	1055

This set demonstrates the importance of surfactant selection in this series. Although only 3% of the resin blend, the surfactant choice has a huge influence on burn characteristics of this type of foam. Surfactant 2 clearly is the best choice in this formula. In an attempt to explain this phenomenon, FITR tests were performed on two cured foam samples, the control made with Surfactant 2, and a cured sample made with Surfactant 3. The two spectra generated are shown in figures 6 and 7.

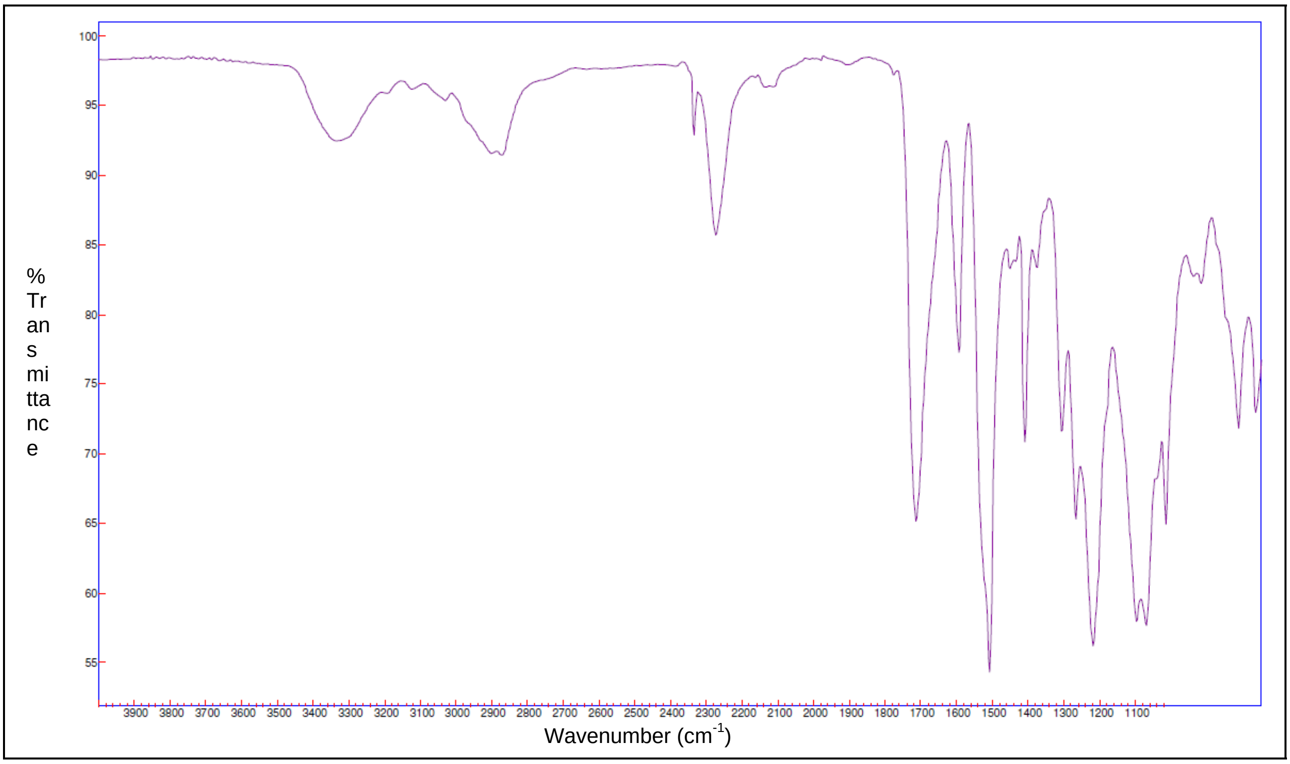

Figure 6 – FTIR Spectrum of 14B10 Made with Surfactant 2

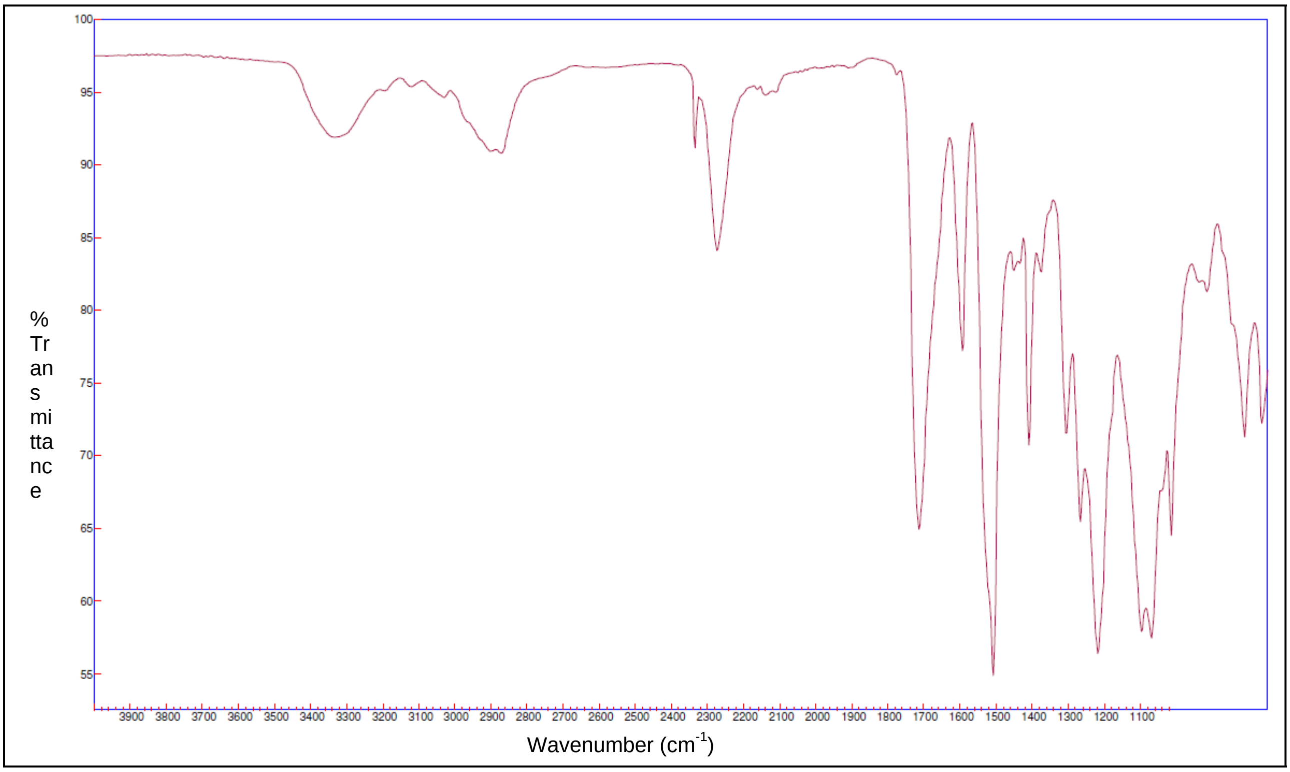

Figure 7 – FTIR Spectrum of 14B10 Made with Surfactant 3

Even though there is a large difference in burn characteristics, the FTIR spectra of the two cured foam samples are identical. This means that FTIR analysis cannot be used to explain the difference in burn characteristics.

In the next set, some polyester polyols were evaluated. The burn results are in Table 24.

Table 24 – 14B10 Burn Results Polyester Polyols Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Polyester Polyol 2)	25	360
Polyester Polyol 1	30	600
Polyester Polyol 3	30	650
Polyester Polyol 4	30	685

In this set, the polyester polyol in the control, Polyester Polyol 2, had the best burn characteristics even when put up against three other commercially available polyester polyols. This set of data shows that polyol selection is very important to burn characteristics in this type of formula.

The last set to be analyzed is the catalyst. The burn results are in Table 25.

Table 25 – 14B10 Burn Results Blowing Catalysts Only

Sample	E-84 Flame*	E-84 Smoke*
Control(Blowing Catalyst 2)	25	360
Blowing Catalyst 1	25	390

The results show a slight advantage towards Blowing Catalyst 2, but 14B10 with Blowing Catalyst 1 also performed well.

CONCLUSIONS

The optimum ingredients for fire rated foams will vary depending on the type of foam that is formulated. For high index boardstock foams, only a small amount of TCPP, around 5% is necessary for good burn characteristics. The high degree of trimerization means that the foam will achieve good burn characteristics without the need for a brominated flame retardant. Of the four blowing agents tested, ecomate® provided the best burn characteristics in a high index polyurethane foam. The high index foam will maintain good burn characteristics with many different surfactants. Finally, a well suited polyester polyol and a strong trimerization catalyst will result in a foam with good burn characteristics. Trimer ring content could be checked by FTIR if necessary.

For a medium index foam, a fair amount of TCPP should be used in combination with a non-reactive brominated flame retardant. FTIR analysis has shown that using reactive brominated flame retardants will greatly reduce trimer formation which is necessary for good burn characteristics. Of the blowing agents tested, ecomate® gave foams with the best burn characteristics. A medium index foam will still have good burn characteristics with many different surfactants, but proper selection is still necessary for optimization. Note that Surfactant 1 worked best in the study. Like the high index foam, proper selection of polyester polyol and trimer catalyst are necessary for good burn characteristics.

For a low index foam, a reactive brominated flame retardant works best for burn characteristics. Of the blowing agents tested, ecomate® again had the best burn characteristics. Proper surfactant selection is critical for a low index foam as the above experiments showed that selecting the wrong surfactant will result in poor burn characteristics. Also very important is the selection of the right polyester polyol. The above experiments tested four polyester polyols, but only one worked well in the formula. In low index formulas, FTIR cannot be used to determine why a foam had good or poor burn characteristics.