Benefits of spray polyurethane foam in commercial applications

When it comes to enhancing the performance of a given building design, not many construction materials can compare to spray polyurethane foam (SPF) insulation. SPF is an ideal insulation material for architects when energy efficiency and code compliance related to air tightness and thermal performance are important. Both open cell and closed cell SPF technologies provide an effective thermal and air control layer as an integral part of the building envelope. The air sealing properties, low thermal conductivity, and design flexibility make SPF the all-in-one solution for architects and builders responsible for insulating residential, commercial, institutional, military, and industrial buildings.

1. Knowing what type of SPF to choose

There are two basic types of SPF technology commonly used in commercial construction today: open cell SPF and closed cell SPF. Depending on the type of commercial construction project, it is important to understand which technology aligns with the design objectives for each application. Although both open cell SPF and closed cell SPF offer superior insulation performance, the two types of products are not necessarily interchangeable.

1.1 Choosing closed cell SPF

Sometimes called two-pound (2 lb/ft³ or 32 kg/m³) or medium density foam closed cell SPF has a thermal conductivity of less than 24 mW/(m·K). It has a high R-value of around R-6 per inch, allowing a 40 % thinner layer to achieve the same thermal conductivity as most fibrous insulation materials. Closed cell SPF is an excellent air control layer, bulk water barrier, and moisture vapor retarder. It provides structural enhancements to buildings and is effective in all climates. It is typically installed in wall cavities, attics, basements, crawl spaces or on exterior walls **(fig. 1a)**.

1.2 Choosing open cell SPF

Open cell SPF has an R-value comparable to most fibrous insulation materials, around 3.6/inch. It is an effective thermal and air control layer option for wall cavities, attics and crawl spaces **(fig. 1b)**. Usually called low density or half-pound foam (0.5 lb/ft³ or 8 kg/m³), open cell SPF has a thermal conductivity of less than 40 mW/(m·K) and also acts as an effective sound absorber. Open cell SPF is softer and more flexible than rigid closed cell foams. In general, it is best suited for mixed or warm climates. It can be used in colder climates when installed in combination with a vapor retarder.

1.3 Properties of open and closed cell SPF

When properly installed, SPF can be an ideal air control material because it forms a continuous, air tight layer around penetrations like pipes, door assemblies and windows. Additionally, it is structurally strong enough to withstand significant air pressure from inside and outside the structure and

Fig. 1:
a) Closed cell SPF,
b) Open cell SPF

Trent Shidaker
sprayfoam@huntsman.com

Business Manager for Huntsman Polyurethanes
Huntsman Corporation, The Woodlands, TX, USA

is very durable during and after construction.

In addition to thermal and air control layer performance, closed cell SPF offers unique attributes in storm-prone areas by adding structural strength. When applied under roof decks, closed cell SPF can reduce uplift and protect the structure – something critical in areas where hurricane wind speeds can reach 300 km/h.

Relative to closed cell spray foam insulation, open cell spray foam insulation has a higher vapor permeability and higher thermal conductivity, but offers different advantages than closed cell spray foam insulation. For example, open cell SPF is a more economical choice for builders and remodelers, often costing 30 % less to purchase and install. Also, water is the primary blowing agent for open cell SPF, which makes it attractive to building owners interested in environmentally-friendly products.

2. Viable commercial uses

While much emphasis has been placed on improving energy efficiency, indoor air quality and structural durability in residential and commercial construction should not be overlooked.

It is a common assumption that commercial buildings have less air leakage than residential structures; however, according to Tom Kearns, Detailing Manager, The Façade Group, LLC, "air infiltration in commercial buildings is similar to residential structures even though the construction may be different." Infiltration in commercial buildings can have many negative consequences, including reduced thermal comfort, interference with the proper operation of mechanical ventilation systems, degraded indoor air quality, moisture damage of building envelope components and increased energy consumption. Commercial buildings have unique needs that are different than typical single-family or multi-unit residential structures. Heavy usage by retail clients, high turnover of occupants, large utility costs and liability concerns related to structural integrity can impact the economic viability of the commercial building. A better-built structure that has superior durability and reduced operating costs is highly attractive to owners and occupants of commercial spaces.

3. Why architects are choosing SPF

When designing a commercial building, architects must satisfy both the requirements of the locally adopted building codes and also the requirements and budget of the project developer. This challenge affects the entire design of the structure, including building envelope design and heating, cooling and ventilation systems. Complying with energy codes also impacts the materials selected for the building by requiring proper window glazing, enhanced insulation levels and lighting design that will reduce energy use, while providing a comfortable environment for the occupants.

In addition, commercial construction often includes atypical design elements. Architects are often called upon to create large entryways, unique features and specific design elements for commercial buildings. Because SPF can be used for a multitude of purposes, it is often an ideal material for insulating, creating an air control layer or serving as a structural support material in unique building design situations. When evaluating different building materials, design attributes and energy performance expectations, SPF is often a valuable asset in the architect's material selection process for three main reasons: it offers exceptional thermal resistance, it often eliminates the need for a separate air barrier, and it facilitates model energy code compliance with ANSI/ASHRAE/IES 90.1 and the International Energy Conservation Code (IECC).

3.1 SPF as a thermal control layer

The thermal control layer keeps building occupants comfortable and energy costs low. Traditionally, the thermal control layer was simply thought to be the insulation used or specifically the thickness or R-value of the insulation installed in the structure **(fig. 2).** Today, the building science community and energy codes have created awareness that the thermal control layer involves more than simply installing a few inches of fibrous insulation between the studs. A successful thermal control layer must offer complete coverage without gaps, spaces, or compression that can reduce insulation effectiveness.

The thermal barrier must also address conductive heat transfer pathways such as thermal bridging through structural members. Thermal bridging is especially important to mitigate in commercial construction where steel framing is more common. Additionally, SPF does not require brackets and fasteners which also act as thermal bridges to the metal framing assembly.

SPF as a thermal control layer is not an independent material but instead bonds to the structure and becomes an integral part of the building. By adhering directly to the building in a monolithic and continuous layer, closed cell SPF can more easily accommo-

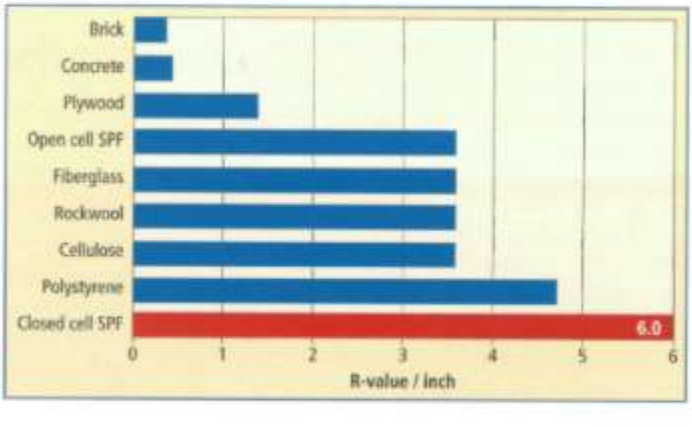


Fig. 2:
R-values of common materials

date unique design features while providing a superior thermal barrier to ensure that comfort and energy efficiency goals are met.

3.2 SPF as an air control layer

In simple terms, an air barrier is a material that controls or stops airflow to and from the interior of the building. It can be comprised of many different materials, but to be an effective air barrier, it must be properly installed to provide a complete shield around all sides of the building. When installed in a structure, the air barrier material becomes part of an air barrier assembly, which combines with the building's windows, doors, and design features to form an air barrier system.

The primary objective of the system is to block the random air movement into and out of a building and its walls and roof assemblies. A facility with unchecked air movement can have a host of problems, including higher energy use and costs, water intrusion, moisture issues and poor indoor air quality.

A unique feature of SPF is that architects can specify it as both a building's thermal control layer and air control layer. This "two-for-one" benefit reduces construction time and material costs, and can help eliminate the challenge of integrating an air barrier and thermal insulation to create an effective wall assembly. There are four key attributes to a well-designed and successfully installed air barrier system: air tightness, durability, continuous coverage, and structural integrity. Architects select closed cell SPF because it can satisfy all four basic requirements of a successful air barrier.

3.3 SPF meeting the model energy codes

One of the primary concerns for an architect is to ensure that each project meets the adopted local building and energy codes. A building that fails to pass a code inspection due to design issues can be an embarrassing, expensive mistake.

The commercial building energy codes ANSI/ASHRAE/IES Standard 90.1-2013 and the commercial provisions of the 2012 International Energy Conservation Code (2012 IECC) require the building envelope to be carefully designed to limit uncontrolled infiltration and exfiltration.

Knowing that various SPF technologies have been validated through independent, ANSI-certified organizations, such as ICC Evaluation Services, LLC, to be compliant with the latest building codes and energy standards, architects specifying SPF can rest assured that their choice of material will make the entire building process easier, and the end product will satisfy the energy efficiency and expectations of the owner and occupants.

4. Why general contractors are using SPF

General contractors are finding that SPF can be an ideal material to choose for commercial building projects for a number of reasons. The general contractor, like the architect, must satisfy building code requirements and the expectations of the client, but there are other considerations that are unique to the general contractor. Time is money for the general contractor, and project delays, cost overruns or long punch-lists can quickly turn a profitable project into a financial loss. When watching the budget of a commercial building project, the general contractor may select SPF for two reasons: reduced construction time and reduced initial building costs.

Because SPF can be applied as a layer of insulation in a single operation, it does not require large crews for installation of mechanical fasteners, glue, netting or any of the other installation requirements encountered when using traditional insulation types. This means that SPF can be quicker and easier to install in most commercial construction settings.

The other financial advantage of using SPF in commercial buildings is that the single application of SPF can serve as both the air control layer and the insulation. What this means to the general contractor is that fewer subcontractors are needed on the job site. With fewer people to manage and less interruption to the building cycle, closing times can be reduced on projects without sacrificing quality.

5. Building types that benefit from SPF

With nearly 5 million commercial buildings and 115 million residential households in the USA, buildings account for almost 40 % of the nation's total primary energy use and 70 % of the electricity used annually.

Much of the energy wasted in commercial and residential buildings is a result of poor air sealing and insufficient thermal insulation. Air sealing is one of the least expensive and most cost-effective measures available to improve a building's energy performance, comfort and durability. By simply sealing uncontrolled air leaks, occupants can expect to realize savings of 10–20 % on heating and cooling bills, and even more in older structures that generally are poorly insulated or were built without continuous air barriers.

In commercial buildings, a well-designed and properly installed air barrier assembly can result in an even greater energy savings potential. According to simulations by the National Institute of Standards and Technology (NIST), air barrier systems in commercial buildings are estimated to reduce air leakage by up to 83 % and can reduce natural gas consumption by more than 40 % and electrical use by more than 25 %.

Although SPF can provide benefits to all styles of commercial buildings, there are several types where SPF can provide exceptional value, including schools and education facilities, healthcare facilities, offices, and hotels.

5.1 SPF in schools

Public and private education campuses can greatly benefit from SPF, whether the project involves new construction or retrofitting and updating an existing building. Schools often are on fixed budgets, and, for public education settings, they have to balance resources between upgrades to the physical building and educational programs. SPF reduces energy consumption and can help save on operational costs associated with heating and cooling.

Some types of closed cell SPF are Greenguard indoor air quality certified and thus intended for use in schools, daycares or other environments where children spend significant periods of time.

5.2 SPF in healthcare facilities

Hospitals are enormously complex buildings with many unique requirements. One of the main elements of the energy savings involves properly sizing the mechanical equipment after air sealing and insulating the entire building envelope. By reducing the infiltration rates of the building and properly sizing the heating, cooling and ventilation system, hospitals in all climate zones can reduce energy loads related to climate control.

Another important contribution SPF can make to health care facilities involves restricting moisture, outdoor allergens and pollutants. The water vapor retarding qualities of SPF help reduce the chance of condensation and mold growth. SPF is also an excellent sound barrier, adding extra value by making recovery rooms in hospitals quieter and less stressful for patients.

5.3 SPF in offices

According to a study conducted by the US DOE, as office temperature rises, productivity decreases an average of 2 % for every degree over 77 °F (25 °C). In practical terms, this means that keeping cool can make both the worker and the bottom line happy. While mechanical ventilation can help regulate the room temperature, heat loss through poor air barriers and insufficient insulation can account for up to 40 % of a building's heating and cooling costs. Also, office buildings are usually steel frame structures which make them vulnerable to thermal bridging. Because SPF does not require metal fasteners and can continuously cover existing thermal bridges, heat transfer associated with thermal bridging can be controlled by using SPF.

5.4 SPF in hotels

Hotel room comfort is largely left to the occupants which can lead to high energy costs as guests adjust heating and cooling demands at will. However, the more consistent the air temperature inside the room, the lower the utility bills will be for the building operator and owner. Often hotels are constructed with only the minimum amount of insulation and air tightness required by building code at the time of construction. By using SPF to create a complete and continuous air control layer, hotels can reduce air infiltration and help maintain a more comfortable space for guests **(fig. 3)**.

6. SPF uses in exterior applications

When applied to the exterior of commercial buildings, in either new or retrofit situations, SPF can greatly reduce energy use, air infiltration and water intrusion. The two primary areas where SPF is used on the exterior of buildings are walls **(fig. 4)** and roofing applications.

6.1 SPF in exterior walls

One of the positive attributes of SPF is that it is a very versatile building material. SPF is compatible with many wall types and can be sprayed onto the exterior sheathing in new construction projects or between stud cavities in retrofit situations. SPF-insulated buildings have superior thermal performance due to the air barrier properties as well as reduced thermal bridging through the studs. In addition, studies have found that SPF can improve the structural integrity of the building in areas of high wind events by increasing the strength of the framing structure.

One of the most important attributes of closed cell SPF in external wall applications is that it is an effective water barrier as well as an air control layer. Reducing moisture intrusion through the wall, whether in vapor or liquid water form, is critically important for the long-term durability of the structure and health of the occupants.

▼ ***Fig. 3:** Closed cell SPF being applied to a hotel in Washington, DC, USA*

6.2 SPF in roofs

Roof failure is a primary cause for water intrusion into the building, and traditional methods of removing and replacing roofing material can be expensive. As a re-roofing material, SPF is applied directly on the existing roof structure. It provides two important benefits to a building through increasing the insulation value and waterproofing. Further, the application of SPF to an existing roof structure is simple and fast. The expanding foam is simply applied directly over the existing metal, wood, concrete, membrane or built-up roofing material. Once the SPF has been applied to the proper thickness, a protective layer of elastomeric coating or ballast, such as gravel, is applied over the insulation. This combination of foam insulation and protective layer produces a durable, weather-resistant surface that is strong enough to walk on.

7. SPF uses in interior applications

When installed on the interior of walls or as part of the floor system, SPF is an integral part of the overall design strategy to improve comfort, indoor air quality and durability and to reduce energy bills. Both walls and floors can be places of air infiltration and have the potential of water intrusion, especially in the form of vapor. SPF in these areas can help promote a healthier and more durable space for the occupants.

7.1 SPF in interior walls

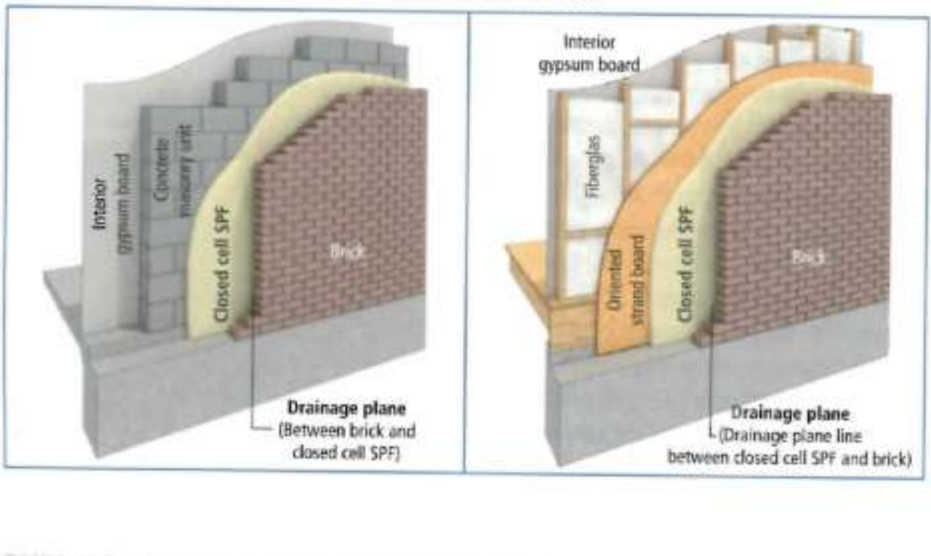
Interior walls in commercial buildings can benefit from SPF in a number of ways, including noise reduction and isolating specific areas of the building from adjacent work spaces. Conference rooms, executive offices and human resource departments are all areas in commercial office buildings where sound proofing is critical in order to maintain a professional atmosphere. Open cell spray foam has strong sound reduction properties, often utilized in recording studios to mitigate sound intrusion. Reducing sound transmission within a commercial building is also important in manufacturing facilities that operate noise-generating machinery. Other buildings that could benefit from noise reduction between interior walls include hospitals, hotels, and schools.

7.2 SPF in floors

Similar to the challenges of interior walls, floors can benefit from reduced noise transmission and air infiltration when SPF is applied. This is especially true in office buildings and hotels, where sound transmission through the floor can be especially disruptive.

Air infiltration through floors is also a concern if they are above crawl spaces. Using SPF as an air and water vapor control layer will reduce energy use and also protect the structure from mold and rot due to water damage.

▼ **Fig. 4:** *Typical examples of SPF usage in commercial wall assemblies*



8. Benefits when using SPF

8.1 Overall energy savings when using SPF

The financial benefits of using SPF in commercial construction are primarily recognized in two specific areas: overall construction cost savings and annual savings through energy conservation. Other financial benefits of selecting SPF as an air control layer and insulation material include increased productivity through a more comfortable work environment, improved air quality, and the increased property value of a more durable and energy efficient building.

8.2 Reduced construction costs with SPF

For the builder or general contractor associated with new or retrofit construction, SPF can offer financial value to a project. First, because SPF can act as an air control layer and thermal control layer, fewer trades or subcontractors are needed to complete a project. Reducing the number of trades required to complete a project not only reduces the number of days the project takes to complete, but also reduces the likelihood of delays due to scheduling challenges.

Another way that SPF helps reduce construction costs is that from a material standpoint, closed cell SPF is the insulation material, air control layer and water barrier in one. By themselves, each of these materials would require sourcing, delivery, storage and then either glue or mechanical fasteners to install.

8.3 Energy savings with SPF

Probably the most well-known benefit of SPF is its ability to be a superior air control layer and thermal insulation material. These attributes result in a host of benefits to the building, but the financial savings through reduced energy consumption are especially attractive to occupants and owners.

Buildings insulated with SPF typically require 30 – 50 % less energy to heat and cool **(fig. 5)** compared to buildings insulated with traditional fibrous products, such as fiberglass and cellulose (Source: DOE).

9. Hurricane winds and the benefits of SPF

Hurricane winds are unique and pose a specific threat to wooden frame built commercial buildings and traditional roof systems. First, the sustained winds from a hurricane can last for hours with occasional gusts up to 50 % greater than sustained air speed. This means that a category 2 hurricane could have gusts that are equal to category 4 strength. Also, because hurricanes move slowly, wind direction changes slowly as the storm passes. This means that any weakness in the roof system will eventually have to face the brunt of the storm.

Higher wind speeds, in general, can cause a reduction in air pressure as they flow over objects, and during a hurricane, air speed on the roof can be two times the sustained wind speed on the ground. During strong gusts, on relatively flat roof surfaces where the wind is flowing more than striking, air pressure can quickly drop as air speed increases.

This loss of air pressure can act as a vacuum and start to pull roofing materials into the air stream, where the direct force of the wind can immediately sweep them away. The dynamics of simple air pressure against the exterior of the house can create incredible pressure and uplift on a roof and result in extensive damage. Additionally, internal pressures cause roof failures in hurricanes as well.

In 2007, Dr. David O. Prevatt conducted a study at the University of Florida's Department of Civil and Coastal Engineering to determine how closed cell SPF could be used to increase the structural integrity of roof assemblies during severe weather events like hurricanes. The study found that the fillets of SPF increased wind uplift resistance an average of two times, while the 3 inch fill increased it three times the uplift capacity of roof panels fastened using conventional mechanical fasteners and nailing patterns. In fact, roofing sections with closed cell SPF applied as an adhesive were able to withstand air pressures found in a category 4 hurricane.

10. Classification codes for SPF

10.1 ICC Evaluation service report (ESR)

When choosing a brand of SPF to use, it can be helpful to research the product through industry-trusted resources. The International Code Council (ICC) has a subsidiary called the ICC Evaluation Service that evaluates building material products and also vets the materials to see if they are acceptable or within compliance to various industry codes and standards. Generally, the building material manufacturer will request that their product be evaluated and then use the report as a basis for providing technical information and product validation to the industry.

When selecting SPF in a building project, it is important that the manufacturer provide an Evaluation Service Report (ESR) of the SPF so that the architect, engineer and builder will be able to properly specify the installation of the material in accordance with related codes and industry standards.

10.2 Certified applicators

Trade organizations often manage certification programs for their members in order to maintain a high level of installation quality in the work force. This is also true for SPF. The Spray Polyurethane Foam Alliance (SPFA) has created a certification program specifically for spray foam applicators. The program was developed in compliance with the ISO 17024 standard of the American National Standards Institute (ANSI), meaning that holders of these certifications have passed a very specific series of required tests in order to validate their expertise in their field. Safety, installation practices and proper applications for SPF are all part of the certification program.

11. Sustainable building practices and SPF

Whether it is "green" building or "sustainable" building, the push to create more durable, energy efficient structures that generate less waste during and after construction remains a priority for many builders, developers and architects. Because of its high R value and low air permeability, SPF can significantly help achieve sustainable goals in commercial building projects.

From an energy savings standpoint, SPF is on the front line of conservation of natural resources and reducing greenhouse gases. Buildings are the largest user of energy in the USA today. According to the US DOE, buildings account for more than 40 % of all energy used in the USA annually, and over 40 % of that energy is used for heating and cooling. Based on current building stock, up to 30 % of the energy used to heat and cool buildings is lost through the building envelope as a result of inefficient air barriers and poor insulation levels. Building with SPF can greatly reduce energy loss through the building envelope while also providing comfort for the occupants.

To determine the true sustainable attributes of SPF, the Spray Polyurethane Foam Alliance (SPFA) initiated a life cycle assessment (LCA) to evaluate the environmental impact of SPF formulations used in residential and commercial buildings. This study is the first comprehensive LCA of spray foam insulation conducted in North America. The entire SPF life cycle consists of cradle to-end of life phases for making, processing, transport-

Fig. 5: *Buildings insulated with SPF typically require 30–50 % less energy to heat and cool*

ing, installing, using and, finally, disposing of spray foam insulation. The results of the study showed that the energy and environmental benefits from SPF use in new commercial roofing retrofits far outweigh the embodied energy and embodied environmental impacts. The study also concluded that the energy and impacts invested to make, install, transport and dispose of the insulation at end of life are minimal compared to the substantial use-phase benefits.

12. Conclusion

Whether the objective is to increase energy efficiency, meet or beat sustainability goals, provide sound insulation, create a superior air control layer or improve structural integrity in high wind areas, SPF is a proven asset to any builder or architect's path to success. By matching the needs of the structure with the performance attributes of SPF, almost any new or existing commercial building can benefit from SPF.

Global Overview of the Spray Polyurethane Foam & One Component Foam Markets

New market study from IAL Consultants

IAL Consultants has published the fourth edition of its report on the markets for spray polyurethane foam (SPF) and one-component foam (OCF). This study updates the information included in the previous study published in 2012. The information contained in this report has been extensively revised through a programme of interviews throughout the industry during the first half of 2014, which led to IAL Consultants significantly revising its APAC data.

The report contains data on the production of both SPF (in tonnes) and OCF (in tonnes and number of cans equivalent) in 2013 and forecast production for 2018 split by the three major geographic regions (Americas, EMEA and Asia-Pacific) and a total of 57 subregions and countries. In addition, estimated demand in cans for both product groups in 2013 is provided for each region, for SPF segmented by type of application.

Spray polyurethane foam

According to the study, despite the global economic slowdown, the demand for SPF continues to grow. Unlike in the past, when the Asian region was driving the demand, today the high growth rates recently experienced in the USA, the largest global producer of SPF second only to China, have had a knock-on effect on the global production volumes recorded. There, the mounting levels of SPF being used have been attributed to the superior characteristics of polyurethanes as well as non-traditional application areas, such as wall insulation, increasingly captivating the construction industry's attention.

Many of the economies of Asia-Pacific are experiencing sluggish growth, and the demand for SPF has much mirrored this, says IAL Consultants. Concerns raised in the past in China regarding the flammability of insulation materials led to an interim ban on the use of spray foam in occupied buildings, further slowing down its demand in the market. Instead, in the mature markets of Western Europe, the need for improved levels of energy efficiency in existing buildings is propelling the demand. Huge potential remains in emerging East European nations such as Russia, where there is still a large amount of existing residential and commercial building stock in need of improved insulation.

In 2013, the total global production of SPF stood at around 600,000 t. This is anticipated to reach 820,000 t by 2018, equivalent to an average annual growth of 6.5 %.

One-component foam

The sound price-quality relationship of OCF means that alternative products in the market are generally overlooked and thus the demand continues to enjoy steady growth. The production now stands at 534.5 million cans and, by the end of 2018, 667.7 million cans are expected to be manufactured globally, equating to a CAGR of 4.6 %.

Over the years, the production of OCF cans has shifted away from Western Europe to economies where labour is less expensive, making China the world's largest producer. Manufactured cans are then easily exported for their use elsewhere. Nonetheless, overall, EMEA still represents the largest region in terms of production volumes (55 % of the total global production), where most of the production is concentrated in Eastern Europe – in particular in Estonia and Poland. As such, Europe is considered the most knowledgeable and demanding market for OCF, and new developments are seeing the first wave of low-MDI content OCFs appearing in the most stringent European countries.

The report "Global Overview of the Spray Polyurethane Foam & One Component Foam Markets" is available from IAL Consultants, priced at EUR 3,500 for a single hard copy edition.

Contact: Cathy Galbraith
E-mail cgalbraith@brggroup.com

Optimization of spray polyurethane foam with isocyanate compatible silicone surfactants

Traditionally, silicone surfactants are used to optimize the performance characteristics of high pressure two-component spray polyurethane foam systems (SPF). The key features of the silicone surfactants are emulsification of the individual raw materials, overall nucleation potential, cell-regulation, and adequate foam stabilization until sufficient curing occurs. Typically, these additives are formulated into the polyol resin blend while the isocyanate is left unmodified. Considering the relatively high surface tension of the isocyanates used in the production of SPF, this study addresses SPF optimization when formulating surfactant into the isocyanate. In our investigation a number of silicone surfactants are evaluated for their ability to significantly reduce isocyanate surface tension and optimization of SPF processing and properties. SPF systems prepared with isocyanate without silicone surfactant versus isocyanate containing silicone surfactant are compared and contrasted.

1. Introduction

High pressure two-component spray polyurethane foam insulation (SPF) is a spray applied insulating foam that is installed as a liquid then expands many times its original size [1]. The SPF material is manufactured at the construction site by the contractor installing the insulation [2]. The SPF is produced by the mixing of two components referred to as A-side and B-side. The A-side consists of polymeric diphenylmethylene diisocyanate (pMDI). The B-side typically is a blend of several raw materials including polyol resin, catalyst, flame retardants, blowing agents, and additives such as silicone surfactants. The mixing of these two components is conducted by a high pressure spray foam machine, which pressurizes and heats both the A-side and the B-side prior to being delivered independently to the spray gun. Upon pulling the trigger of the spray gun, A and B mix very rapidly by impingement mixing in the interaction chamber of the spray gun tip. The mixture is sprayed on the substrates to be insulated. Within seconds the pMDI and polyol resins react, gel, expand, and cure into a polyurethane solid foam, which is adhered to building materials it is sprayed on.

Dr. Carsten Schiller
carsten.schiller@evonik.com
Dr. Christian Eilbracht
Comfort and Insulation,
Evonik Industries, Essen, Germany

Ray Geiling
Evonik Industries, Hopewell, VA, USA

Paper, Polyurethanes 2013 Technical Conference,
23–25 September 2013, Phoenix, AZ, USA,
CPI, Center for the Polyurethanes Industry

Published in RubberWorld, October 2014, vol. 250, no. 7

Published with kind permission of RubberWorld,
Lippincott & Peto, Inc., Akron, OH, USA

Fig. 1:
An example where improved SPF flow could be beneficial at improving gap fill: a) attic ceiling of a 1930's home in Richmond, VA; b) gap formed by the roof deck and roofing truss; c) close up of the gap formed between the roof deck and roof truss

Since SPF is applied as a liquid, compared to other insulating materials, it has the unique ability to mold and contour to the shape of the substrate it is applied. Air barrier properties of the structure being insulated are improved by sealing the structure from air leaks. This feature is enhanced by filling irregular gaps of the construction that would otherwise allow air infiltration, while providing a relatively high R-value per inch of insulation installed [1].

The optimization of SPF physical properties such as overall density, R-Value, percent closed-cell content, etc. is important. However, equally important is the optimization of the application performance, which facilitates the ease of use experienced by the spray foam applicator. Some examples include robustness of the formulation in various temperature conditions, how well the foam adheres to the substrate, how easily the foam flows into irregular cavities to fill gaps **(fig. 1)**, and the amount of gun plugging that occurs to name a few.

Fig. 2: *a) DFM-170 paper bucket (volume: 5 L) from International Paper with a 32 mm hole cut at the bottom; b) SPF system tested for flow. The foam protruding from the bucket represents the amount of foam flowed for that sample.*

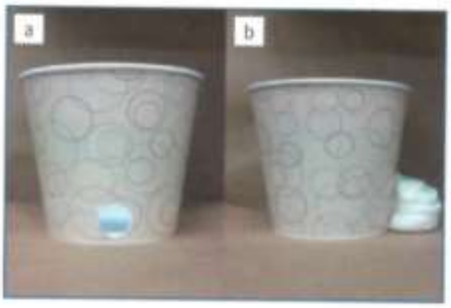


Fig. 3: *SPF samples from flow testing. The sample on the left represents a low flowing sample versus a high flowing sample on the right*

It is known that silicone surfactant technology can significantly improve the spreading area of a liquid over a substrate. This is seen in other industries such as paints, inks, and coatings [3]. Silicone surfactants improve the spreading of liquids by significantly reducing the liquids surface tension. Considering that SPF is spray applied as a liquid that very rapidly becomes a solid, this study considers the phenomenon of lowering the dynamic surface tension of the SPF system to improve flow properties.

Tab. 1: *Standard 32 kg/m³ closed-cell wall SPF formulation*

Ingredient	%
Polyester polyol blend	69.2
Flame retardants TCPP & PHT 4-Diol	15
Catalyst package DMEA & PMDETA	4.5
Tegostab B 8408	1
HFC-245fa	8
Water	2.3

Tab. 2: *Polymeric methylenediphenyl diisocyanate (pMDI) properties*

pMDI	Value
Isocyanate equivalent weight	135
NCO content	31
Functionality	2.7
Viscosity @ 25 °C	190

Fig. 4: *a) spray table constructed for holding the Graco Fusion AP spray gun and the DFM-170 bucket; b) spray table with mounting bracket for holding the spray gun*

It is thought that by improving the amount of flow the SPF system exhibits while being sprayed will greatly impact its ability to fill gaps, especially in irregular construction configurations. This feature should increase the ease of use experienced by the applicator. It is also theorized that by improving the flow characteristics of the SPF system, the air purging mechanism will more efficiently prevent or significantly reduce gun clogging and plugging, thus further increasing the ease of use experienced by the foam applicator.

The focus of this evaluation is to investigate a special class of organic modified silicone surfactants which are considered isocyanate compatible. For the purposes of this paper, these surfactants are defined as having no hydroxyl functional groups. This feature prevents a reaction between the isocyanate and silicone surfactant. This investigation will specifically address improvement in SPF flow properties.

This investigation evaluates the impact of adding surfactant directly to the pMDI as compared to adding it to the polyol blend. The overall goal is to optimize the flow properties of a 32 kg/m³ closed-cell SPF system while maintaining good overall physical properties. For the purposes of this study, Evonik has developed a new flow testing procedure for comparing and contrasting flow performance.

2. Experimental

2.1 Formulation

A standard 32 kg/m³ closed-cell wall SPF formulation is shown in **table 1.** The system is optimized with 1 wt% Tegostab B 8408 polyether modified silicone surfactant formulated into the polyol resin blend. The polyol blend is reacted with a polymeric MDI isocyanate **(tab 2).**

2.2 Spray foam equipment

The SPF was applied by using a Graco Reactor E-20 plural component spray foam machine, a Graco Fusion Air Purged Gun, and a 01 spray tip. The temperatures for A-side, B-side, and hose were set at 43 °C or 49 °C. The static pressure for A- and B-side was set to 83 bar resulting in a dynamic pressure of 70 bar. At raw material temperatures of 43 °C, a gel time of 4 s, and a tack free time of 9 s were observed. At 49 °C, the reactivity increased to 7 s tack free time.

2.3 Physical properties

Samples were prepared for measuring physical properties. Throughout the evaluation samples were prepared at 43 °C and 49 °C to determine the effect of temperature on physical properties. Temperature settings were equally set for A-side, B-side, and hose for each test. Sample preparation was conducted in a single pass at a thickness of 5 cm. Each sample was allowed to post cure for 24 h prior to measuring physical properties. Density, k-factor, R-value, and percent closed-cell content were measured.

2.4 Flow testing (Evonik flow test bucket)

A key component to the Evonik SPF flow test is the substrate which is sprayed for measuring flow. In order to simplify the test and allow for multiple flow test samples to be prepared in a relatively short amount of time, a DFM-170 food bucket (volume: 5 L) supplied by International Paper was used. A drill saw bit was used to cut a 32 mm diameter hole in the side of the bucket. The hole was cut flush with the bottom of the bucket's floor **(fig. 2)**. The walls of the bucket represent the confines of a stud wall cavity. The hole in the bucket represents a constricted gap opening which is perpendicular to the direction of spray **(fig. 3)**.

2.5 Flow testing sample preparation

In order to control variables in application technique, a simplistic spray table was designed to hold the Graco Fusion AP spray gun at the same distance for each sample prepared. The table supports the gun placement with a mounting bracket **(fig. 4)**. This configuration gave a spray distance of 46 cm between the spray gun tip to the bottom of the DFM-170 bucket. The spray pattern of the SPF sprayed fit into the bucket without overspray at this distance. Each sample was sprayed using a 2 s shot time. This was controlled by the technician using a stop watch for each trigger pull. The Graco E-20 Reactor was set in the stroke mode

$$\%\ \text{flow} = \frac{\text{Amount of SPF flowed (g)}}{\text{SPF sprayed weight (g)}} \times 100\ \% \qquad 1$$

$$\%\ \text{improvement of flow} = \frac{\%\ \text{flow sample} - \%\ \text{flow standard}}{\%\ \text{flow standard}} \times 100\ \% \qquad 2$$

Tab. 3: *Isocyanate compatible surfactants selected for formulating into pMDI*

Sample	A-1	A-2	A-3	A-4	A-5	A-6
Siloxane chain length	Medium	Low	High	Medium	Low	Medium
Degree of backbone modification	Medium	High	Low	Medium	High	Medium
Polyether chain length	Low	Low	High	Medium	Medium	Medium
Propylene oxide content	Low	Low	High	Medium	High	High
Additional organic pendants	No	No	No	No	No	Yes

Tab. 4: *Physical foam properties of standard sprayed at 43 °C versus 49 °C*

Surfactant in polyol	pMDI	Temperature	% flow	Density	k-factor	R-value	% closed-cells
1 % Tegostab B 8408	Standard	110 °F	3.7	1.96	0.1523	6.6	95
1 % Tegostab B 8408	Standard	120 °F	3.8	1.97	0.1524	6.6	91

Tab. 5: *Performance impact of adding 1 % surfactant to pMDI*

Tegostab B 8408 in polyol	1 % surfactant in pMDI	% flow	% improved flow	R-value	% closed-cells
1 %	None – standard	3.7	0	6.6	95
1 %	A-1	3.5	–10	6.6	98
1 %	A-2	4.6	18	6.5	94
1 %	A-3	4.6	18	6.4	95
1 %	A-4	5.5	41	6.5	97
1 %	A-5	6.5	67	6.5	96
1 %	A-6	7.5	92	6.5	93

Tab. 6: *43 °C processing temperature: evaluation of 0 %, 0.25 %, 0.50 %, and 1.0 % A-6 formulated into pMDI*

% Tegostab B 8408 in polyol	% A-6 in pMDI	% flow	% improved flow	Density	k-factor	R-value	% closed-cells
1	0	3.7	0	1.96	0.1523	6.6	95
1	0.25	4.6	24	1.95	0.1529	6.5	92
1	0.5	4.5	22	1.96	0.1517	6.6	93
1	1	7.5	92	2.01	0.1539	6.5	93

Tab. 7: *49 °C processing temperature: evaluation of 0 %, 0.25 %, 0.50 %, and 1.0 % A-6 formulated into pMDI*

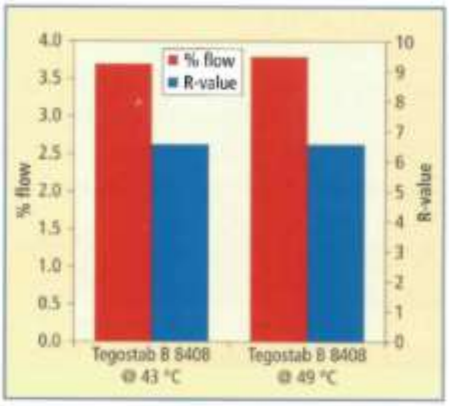
% Tegostab B 8408 in polyol	% A-6 in pMDI	% flow	% improved flow	Density	k-factor	R-value	% closed-cells
1	0	3.8	0	1.97	0.1524	6.6	91
1	0.25	5.6	47	1.96	0.1553	6.5	93
1	0.50	5.7	50	1.93	0.1555	6.4	91
1	1	4.3	13	1.94	0.2109	4.7	68

and the number of machine strokes was recorded for each sample prepared.

2.6 Percent flow measurement

After each sample preparation the amount of foam sprayed was weighed. A scale was used to measure the weight of SPF sprayed and of the amount of SPF which flowed out the 32 mm hole in the test bucket. First, in order to tare the scale an empty test bucket is weighed and the scale, is set to zero. The foam sample was then weighed and recorded as grams of SPF sprayed. Next, the portion of foam which flowed out of the 32 mm hole was carefully cut off with a hack saw. This portion of foam was then weighed and recorded as the amount of SPF flowed. The percent flow of the sample and the improvement of flow were calculated according to **equations 1** and **2.**

Fig. 5: *Percent flow obtained by the standard formulation prepared with standard pMDI at 43 °C versus 49 °C. R-value is also plotted.*



3. *Isocyanate compatible surfactants*

For this study the terminology isocyanate compatible surfactants refers to a class of organic modified silicone surfactants which do not contain any hydroxyl functional groups. These surfactants comprise of a linear polydimethyl siloxane backbone with pendant organic side chains attached to the backbone resulting in a comb-like molecule. By fine tuning its chemical structure the physicochemical properties of the surfactant can be adjusted within wide ranges. We selected a set of six different surfactants, all of them having polyether side-chains made of ethylene oxide and propylene oxide. One candidate had a second type of organic pendants attached to the siloxane backbone in combination with the polyether. **Table 3** characterizes all six surfactants regarding different structural parameters like siloxane chain length, polyether chain length, degree of backbone modification, etc.

4. Results

4.1 Standard pMDI performance

The standard 32 kg/m^3 closed-cell SPF formulation was first sprayed to determine the systems standard performance and used to establish a baseline for comparison. Samples were prepared and tested using the methods previously discussed for measuring physical properties and % flow.

The system was sprayed at 43 °C and 49 °C to determine whether or not the temperature change would impact properties. The samples produced 3.7 % and 3.8 % flow at 43 °C and 49 °C respectively. Additionally, density and insulation values were equivalent at both temperatures. However, at 49 °C the percent closed-cell dropped from 95 % to 91 % **(tab. 4** and **fig. 5).**

4.2 Impact of adding surfactant to pMDI

Isocyanate compatible surfactants outlined in **table 3** were used at 1 % to formulate individual samples of pMDI. These formulated pMDI samples were then evaluated for their impact on SPF flow and for their impact on final SPF physical properties. With the exception of surfactant A-1, all surfactants improved the flow of the SPF system while maintaining good insulation and percent closed-cell properties. At 92 % improvement in flow over the standard formulation, surfactant A-6 significantly improved flow over all other candidates **(tab. 5** and **fig. 6).**

4.3 Performance of A-6 surfactant

Based on the superior flow performance of surfactant A-6, pMDI samples were prepared using 0.25 %, 0.5 %, and 1.0 % A-6. Addi-

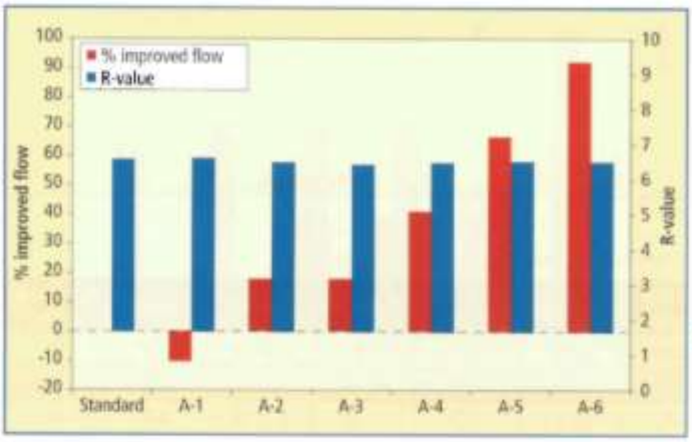


Fig. 6: *Impact on flow and insulation properties when adding 1 % surfactant to pMDI.*

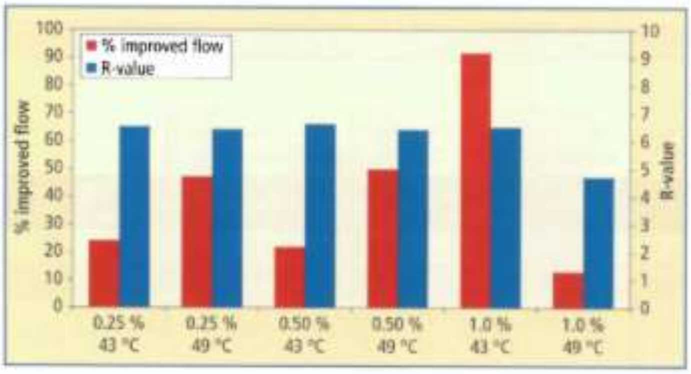


Fig. 7: *Comparing 0.25 %, 0.5 %, and 1.0 % levels of A-6 surfactant formulated into pMDI; impact on flow and insulation value when processed at 43 °C and 49 °C. Percent improved flow is relative to the performance of the standard formulation at 43 °C and 49 °C*

tionally, the effects of changing the processing temperature from 43 °C to 49 °C were evaluated. At a processing temperature of 43 °C A-6 at 0.25 %, 0.50 %, and 1.0 % improved flow by 24 %, 22 %, and 92 % respectively while maintaining density, good insulation value, and percent closed-cell content **(tab. 6)**. However, upon evaluation at the higher temperature of 49 °C A-6 at 1.0 % had a negative impact on flow property, insulation value, and percent closed-cell content dropping from 93 % at 43 °C to 68 % at 49 °C. It is theorized that A-6 becomes less compatible in the SPF system and behaves as a cell-opener at this elevated concentration.

Conversely as compared to the standard formulation at 49 °C, at 0.50 % use level, A-6 flow improved by 50 % with a slight drop in insulation value. The optimal use level of A-6 appears to be in the range of 0.25 % to 0.50 %. Flow is improved up to 50 % while maintaining good insulation value and percent closed-cell content **(tab. 7** and **fig. 7)**.

4.4 Dynamic surface tension and liquid spreading

The work required to extend the interfacial area of liquid is referred to as surface tension [3]. It is known that there is a relationship between surface tension and the ability of a liquid to wet out a substrate. The relationship is that liquid will more easily wet a substrate when its surface tension is much lower than the substrate's surface energy [3]. It is also known that the use of organic modified silicone surfactants at low use levels can significantly reduce the surface tension of liquids.

To help explain the improved flow properties of SPF when prepared with pMDI formulated with A-6 surfactant, the dynamic surface tension was measured of pMDI and pMDI formulated with 0.25 %, 0.5 %, and 1.0 % A-6 surfactant. Dynamic surface tension was measured using a Sita maximum bubble pressure tensiometer. The effect on dynamic surface tension is shown in **figure 8.** The reduction in surface tension improves the flow properties of pMDI **(fig. 9)**. This is a demonstration of 50 µL of pMDI applied to a plastic film. As can been seen in the photograph, the addition of A-6 surfactant significantly increases the area covered by the pMDI sample.

4.5 Evaluation of A-6 surfactant formulated in polyol

Although this study demonstrated significant improvement in flow properties when A-6 surfactant is formulated into pMDI, Evonik wanted to investigate how A-6 would perform when formulated into the polyol and the pMDI was left unmodified. Since 49 °C had previously been a more critical temperature than 43 °C, the evaluation was conducted at 49 °C.

Referring to **table 8** and **figure 10,** flow increases to 353 % versus the standard when A-6 is added at 1 % use level to the standard polyol blend. However, this occurs at the sacrifice of insulation value and percent closed-cell content, 4.7 % and 40 % respectively. An evaluation of using 1 % A-6 in the polyol as the standalone surfactant demonstrates the lack of stabilizing properties, A-6 has for this system as percent closed-cell content drops to 29 %. However, the standard system, which is formulated with 1 % Tegostab B 8408 is further optimized by the addition of 0.25 % A-6. This combination results in 132 % improvement in flow while maintaining good insulation value and percent closed-cell content.

Simply adding an additional 0.25 % of the standard surfactant Tegostab B 8408 currently in the system, flow properties also improved. At an overall use level of 1.25 % Tegostab B 8408 improved flow by 74 %

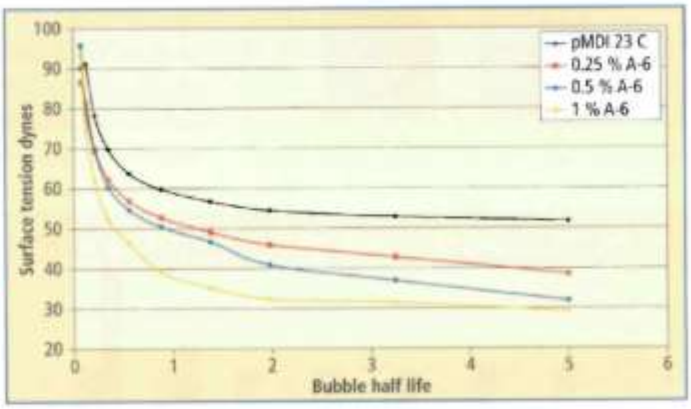


Fig. 8: Comparison of dynamic surface tension of standard pMDI and pMDI formulated with A-6 surfactant at 0.25 %, 0.50 % and 1.0 %

Tab. 8: *Impact of A-6 formulated into the polyol blend*

% Tegostab B 8408 in polyol	% A-6 in polyol	% flow	Flow vs. control	Density	k-factor	R-value	% closed-cells
1	0 – standard	3.8	0	1.97	0.1524	6.6	91
1	0.25	8.8	132	1.93	0.1547	6.5	90
0.75	0.25	8.7	129	1.92	0.1556	6.4	86
1	1	17.2	353	1.97	0.2146	4.7	40
0	1	10	163	1.98	0.2622	3.8	29
1.25	0	6.6	74	1.94	0.1532	6.5	90

Tab. 9: *Comparison of performance when formulating 0.25 % A-6 into the pMDI, into the polyol resin blend, as well as adding additional 0.25 % Tegostab B 8408 (49 °C processing temperature)*

Sample	% flow	Flow vs. control	Density	k-factor	R-value	% closed-cells
0.25 % A-6 in pMDI	5.6	47	1.96	0.1553	6.4	93
1.25 % Tegostab B 8408 in polyol	6.6	74	1.94	0.1532	6.5	90
1 % Tegostab B 8408 + 0.25 % A-6 in polyol	8.8	132	1.93	0.1547	6.5	90

without sacrificing insulation value or percent closed-cell content. However, by addition of 0.25 % A-6 rather than 0.25 % more Tegostab B 8408 the flow is improved to 132 % **(tab. 8** and **fig. 10)**.

5. Conclusions

From this research, Evonik Industries was able to draw some important conclusions. The developed flow test was suitable for comparing and contrasting the flow properties between SPF systems and scenarios. Utilization of this test made it possible to rank a given set of isocyanate compatible silicone surfactants in terms of flow performance and their impact on physical properties. The flow test identified surfactant A-6 as having superior flow properties. Evaluation of A-6 at various concentrations and temperatures revealed that the optimum use level for improving flow while maintaining physical properties is around 0.25 % in pMDI. We found a correlation between dynamic interfacial tension in pMDI and the improvement in flow properties. One might speculate that the specific organic modification of A-6 leads to faster diffusion rates, lower surface tension, and improved flow properties.

Upon further investigation it was discovered that A-6 organic modified silicone surfactant has an even bigger impact when formulated into the polyol resin blend **(tab. 9** and **fig. 11)**. The addition of 0.25 % A-6 surfactant to the standard surfactant (1 % Tegostab B 8408) more efficiently improves flow properties than simply increasing the use level of Tegostab B 8408 to 1.25 %. It is also important to understand that the A-6 structure does not provide enough stabilization in this system to be utilized as a stand-alone stabilizer. Rather the best overall performance is obtained by keeping the standard stabilizer Tegostab B 8408 concentration at 1 % and using A-6 as a flow enhancing additive at 0.25 %.

Additionally, with improvement in flow properties the Graco Fusion AP spray gun appeared to remain cleaner longer and experienced less gun plugging. Although not quantified in this study, it stands to reason that improving flow properties of an SPF system would result in an increase in the efficiency of the air purge gun cleaning mechanism.

Further investigations are necessary to prove whether the results of this study translate into other SPF systems. Assuming this is true, it may be used as a powerful tool to further improve flow properties and reduce gun plugging in SPF just by adding a rather small amount to the formulation.

Fig. 9: *50 µL droplets of pMDI with and without A-6 surfactant. The surface area covered is significantly greater when A-6 is added to the pMDI versus standard pMDI.*

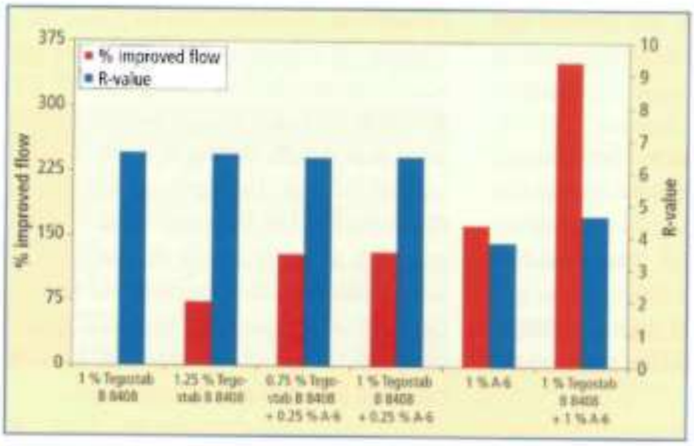


Fig. 10: *Impact A-6 surfactant has on flow and R-value when formulated into the polyol blend. Information is also gathered for the impact of adding additional Tegostab B 8408 to the standard system.*

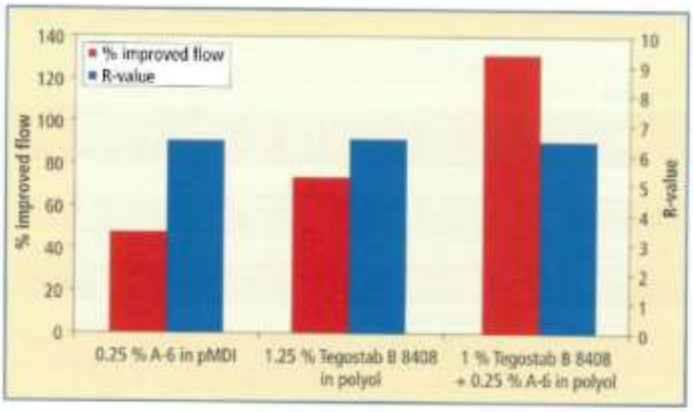


Fig. 11: *Comparison of the impact on flow and R-value when formulating 0.25 % A-6 into the pMDI, into the polyol resin blend, as well as adding additional 0.25 % Tegostab B 8408 (49 °C processing temperature).*

6. References

[1] www.sprayfoam.org

[2] M. Bogdan, J. Ling, D. Williams, "Next Generation (LGWP) of Blowing Agents for Spray Foam Applications"

[3] Tego Journal 3rd edition 2007, Tego Chemie Service GmbH

[4] C. Eilbracht, T. Metz, R. Tauchen, "Easing the Transition Between Blowing Agents in PIR Formulations Through Proper Surfactant Selection", Proceedings of the Polyurethane Expo. 2012 ■