Henri Fennell, CSI/CDT

Henri is an architect and building envelope specialist with over forty years of experience in the construction industry. He was a pioneer in the solar industry, introduced the installation technique for field-applied closed-cell closed-cavity-fill polyurethane foam and has designed and constructed a net-zero energy research structure in Antarctica. He has four energy-related U.S. patents.

HCF foam experience

1. First spray foam project was in 1971
2. Foam manufacturing from 1973 to 1979
3. Foam contracting and BE consulting from 1979 to 2009
   - Developed the method for injecting closed-cell foam on site
   - Installed ~ 5 million pounds of foam
4. Foam and BE commissioning from 2009 to present
5. Noteworthy foam projects include:
   - 1977 net-zero solar project in Boston, The Big Dig, 4 American Ski Grande Hotels in the Northeast, Net-zero energy weather station in Antarctica, The Guggenheim Museum
6. Two US patents and numerous technical papers related to foam & foam QA

Processing QA for Spray-applied Polyurethane Foam (SPF) – New Equipment and Test Shot Method

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Processing “bulk” polyurethane foam

Delivery systems for field-processed bulk spray or injection foam with a high-tech rig

- High-output (10 to 100 #/minute) pressurized or pumped bulk equipment (low-tech and high-tech machine processing equipment)

The chemical reaction of polyurethane foam

The typical processing system

The foam industry has relied on this type of equipment to provide quality processing since 1945 (1:1 ratio and the right pressure and temperature)

Courtesy: Graco, Inc.

Spray guns

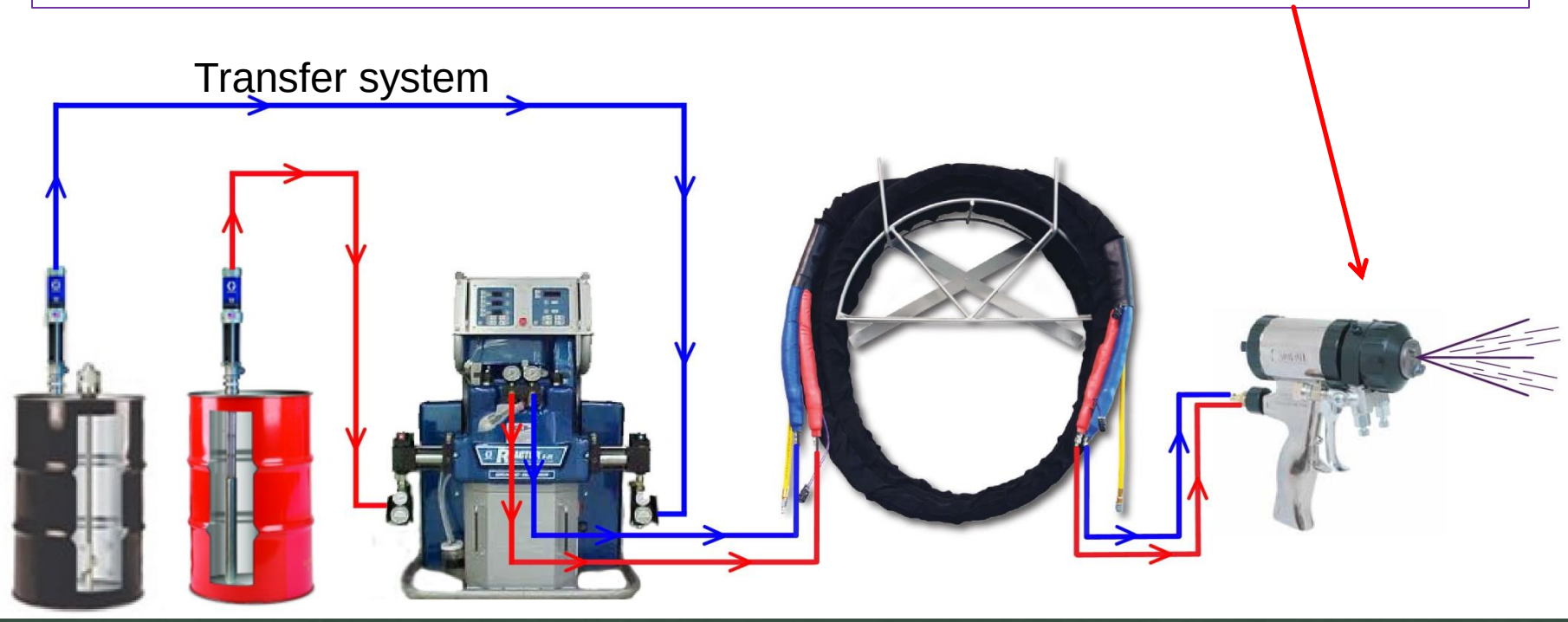
Processing vs. Installation

Processing occurs before the gun

Installation happens after the gun

The processing system

The gun is where it all happens. The chemicals are combined and mixed in the gun. If all of the previous steps are complete, and nothing has changed in the last few feet of hose, we should be dispensing good quality material.



Supply chemicals

Proportioner

Hose assembly

Gun

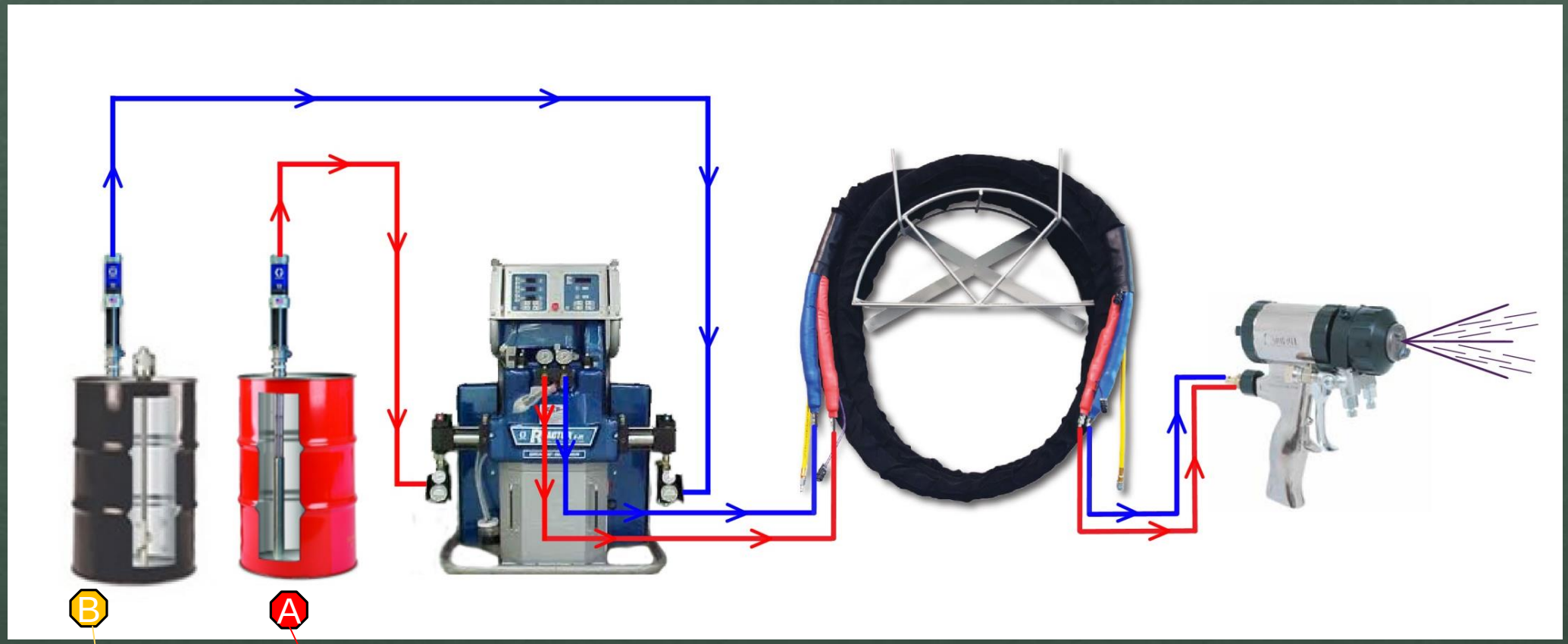
The Installation

The steps in processing high-quality foam

The steps to proper processing

1. Transfer the supply chemicals (75F – 85F) to the proportioner inlet at the proper temperatures, in the proper volumes, and at the proper pressures.
2. Pump the supply chemicals to the gun at the proper ratio, pressures, and temperature (the primary three processing parameters).

The processing system



Pre-conditioning - Measure supply chemical temperatures at the inlets of the A & B transfer pumps

The SPF industry

- SPF is one of the few building materials that is manufactured on site
- There are no standards for SPF installations
- Processing/off-ratio issues are the cause of 85% of the foam failures I have worked on
- Meeting all of the manufacturer's processing parameters is necessary to avoid off-ratio-related IAQ issues
- The manufacturer's three critical processing parameters can be summed up as doing what is required to have the right temperature, pressure, and ratio at the gun

The size of the industry

The following table shows how polyurethanes are used (US data from 2004):[26].

Application	Amount of polyurethane used (millions of pounds)	Percentage of total
Building & Construction	1,459	26.8%
Transportation	1,298	23.8%
Furniture & Bedding	1,127	20.7%
Appliances	278	5.1%
Packaging	251	4.6%
Textiles, Fibers & Apparel	181	3.3%
Machinery & Foundry	178	3.3%
Electronics	75	1.4%
Footwear	39	0.7%
Other uses	558	10.2%
Total	5,444	100.0%

Table 3
U. S. Polyurethane Production by End-Use Market (2014)

	Million Pounds	% of Total
Building and Construction	1,901	35.9%
Transportation and Marine	1,069	20.2%
Furniture and Bedding	1,079	20.4%
Machinery and Foundry	326	6.2%
Appliances	273	5.2%
Packaging	198	3.7%
Textiles, Fibers and Apparel	43	0.8%
Electronics	33	0.6%
Footwear	16	0.3%
Other End Use Markets for Polyurethanes	356	6.7%
Total Polyurethanes Production	**5,293**	**100.0%**

Source: CPI 2014 End-Use Market Survey on the Polyurethane Industry

How many problems are due to processing?

85% of foam failures I see are caused by processing issues

Causes of foam problems*	
Processing	85%
Installation	15%

Improper processing is one cause of IAQ issues

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*Not including problems that are actually building science or design issues

Define the problem

1. Off-ratio processing creates indoor air quality problems
2. Burnout creates indoor air quality problems, but equipment can't address this issue

The purpose of the processing QA is to assure that the proper conditions are achieved at the gun. These are specified in the processing parameters.

Define the problem

1. In the past, equipment technology has not provided feedback that would allow the installers to verify the processing parameters
2. In the past, equipment technology has not automatically shut down the machine when critical processing parameter requirements are not being met

Processing Parameters by method	Manual vs. Automatic verification			FPM triggers automatic shut down
	Manual verification only	Classic machine controls	FPM reporting	
A - Shipping & storage temperature (F)	X	X - Off site		
B - Shipping & storage temperature (F)	X			
Recirculation - required or prohibited	X	X	X	X
Mixing - Adequate or prohibited	X	X	X	X
A - Supply chemical temp. (F)			Coming soon	
B - Supply chemical temp. (F)				
A - Proportioner inlet temp. (degrees F)	X	X	X	X
B - Proportioner inlet temp. (degrees F)	X	X	X	X
Transfer rate/pressure to proportioner			X	X
A - Pressures (PSI)	X	X	X	X
B - Pressures (PSI)	X	X	X	X
A-B pressure difference (PSI)	X	X	X	X
Flow ratio (by volume)			X	X
A - Temperature at proportioner (degrees F)	X	X	X	X
B - Temperature at proportioner (degrees F)	X	X	X	X
Temperature in the hoses (degrees F)	X	Sometimes	X	X
Temperature at the gun (degrees F)			X	X
Length of cure period (hours)	X	X	X	X
Test shot quality	X	X	X	X
X = manual, Pink = Critical feedback not provided, Green = Critical feedback & control provided				

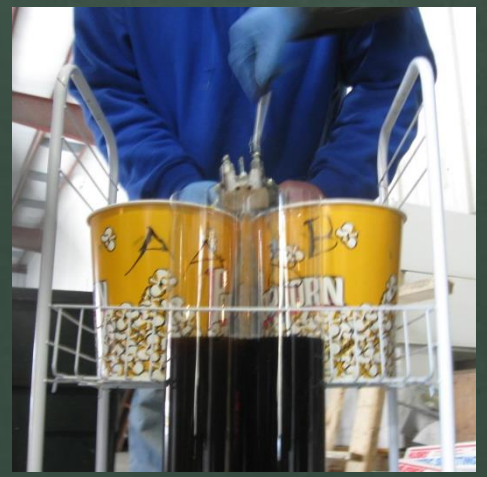
The processing system

The foam industry relies on this equipment to provide processing quality with no feedback about the actual flow ratio

Courtesy: Graco, Inc.

Manual calibration – by volume

E30 pressure set at 750 psi



These two tests are very close – a follow-up test by weight confirmed this is within .4%

Manual calibration – by volume

This one was off by more than this manufacturer's 2% tolerance – chemical temperature was too low

After heating the supply chemicals, the test result was within 1%

This is a snap shot in time, but a worthwhile QA check for equipment performance

< 1%

Manual calibration – by volume

Manual calibration - by weight

This calibration test is within 3% (recirculation block adapter)

This one is off by about 17% - High-stall test verifies that primary pump check valve is not closing

After the repair, the machine was on ratio

Calibration can identify restrictions

Supply-side restrictions

This system was off ratio by about 14% until these kinks were eliminated

Define the solution

1. The equipment must provide feedback, fault protection, and reporting (documentation)
2. Ratio issues can be prevented with equipment solutions

FPM Systems

FPM systems

- What are Fault-protection Process Monitoring systems (FPM systems)?
- Fault-protection means that if the system sensors determine that a measurement is outside of the range of a parameter tolerance, the machine will shut down automatically
- Process means the functions the equipment performs on the supply chemicals until they exit the gun
- In this case, Monitoring means sensing and recording machine functions using equipment rather than by doing it manually

FPM systems

Fault-protection process monitoring systems (FPM systems) have been available for OEM users, but not for field installers until recently

1. PFPI - Ratio monitor (1995)
2. Akurate Dynamics - Delta CPS (2017)
3. Graco - Reactor 2 Ratio Assurance system (2018)
4. Polyurethane Machine Corporation (PCM) -PMC PHD (2019)

QA equipment is standard for OEM applications

OEM monitoring systems

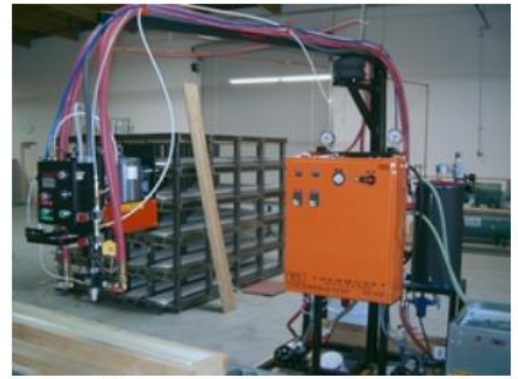
- Home
- Static Mix Models
- Low Pressure Sprayers
- Custom Built Machines
- PMC High Pressure
- Dynamic Mix Models
- Contact Us

MIXZEN M Series Dynamic Mix Machines

Dynamic mixing is required for harder to mix polyurethane's. Most high density rigid foams, flexible foams, and self-skinning foams require either a low pressure dynamic or high pressure RIM machine to process. RIM machines are very expensive, require more electrical power and are much tougher to service.

Experience the MIXZEN M Series advantage! Our helical mix blade turning at 6,900 RPM insures an incredible mix, precision pumps keep ratios within 0.5% and tempering controls maintain critical process parameters and reaction rates. The low pressure laminar flow exiting the mix chamber is ideal for dispensing into shallow open molds.

MIXZYN M40



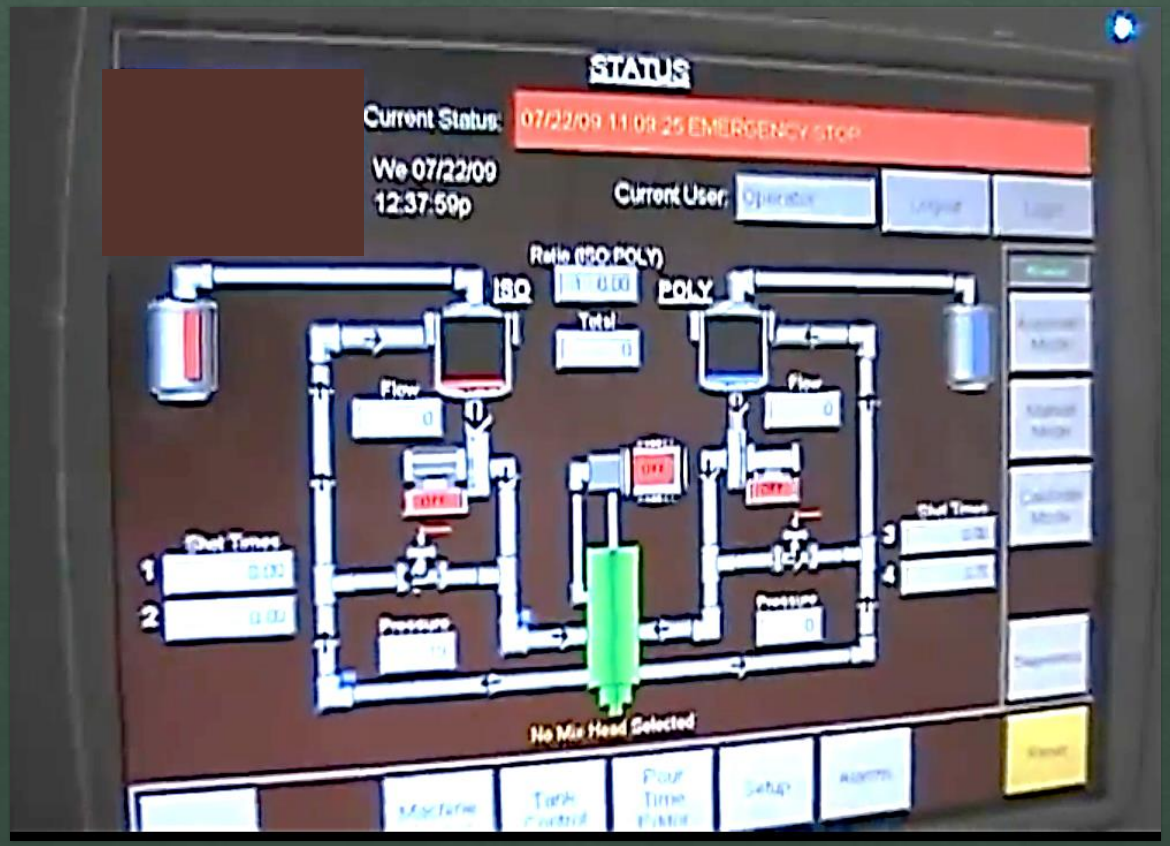
Manufacturing Architectural Foam Trim

Specifications

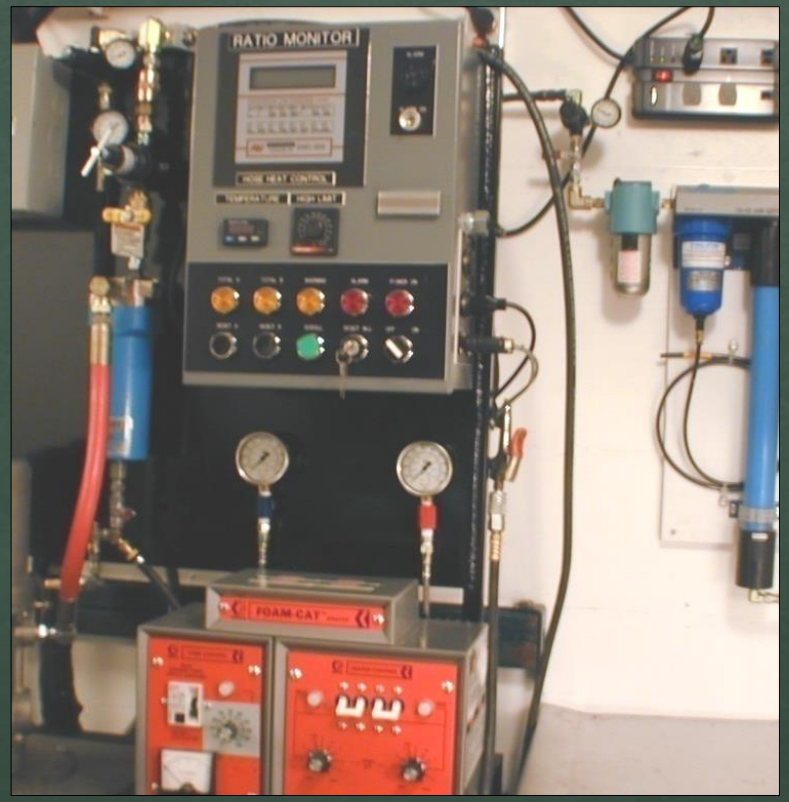
Options

QA equipment is standard for OEM applications

QA monitors with fault-protection capabilities have been in use since 1954



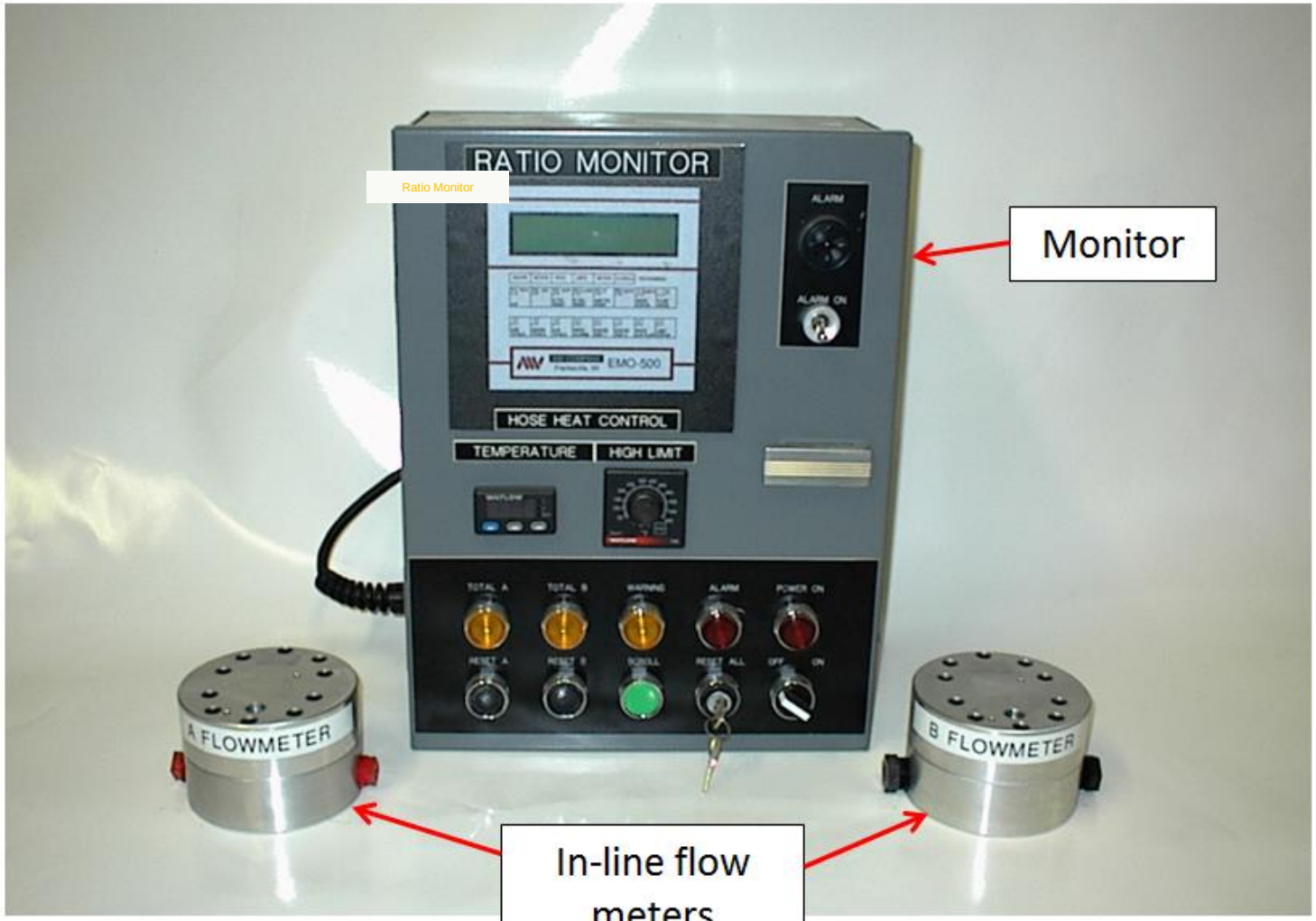
Third-party retrofit FPM systems (1995)



Mobile Spray Rig (Bulk foam)

Automatic ratio and temperature monitor

These are the two main components of a temperature and ratio monitoring system.



Graco Ratio Assurance System (2018)

Control to electric models.

RATIO ASSURANCE SYSTEM

is standard on Reactor 2 elite models.

Updated ADM

- Home screen update to include the real-time ratio value and ratio gauge

ADM Set-up: System Screen

- Updated ADM set-up screen to allow easy configuration of flow meters and enabling alarms

Oval

- Simp
- Ideall

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First seen at SPFA 2019 spray foam Conference

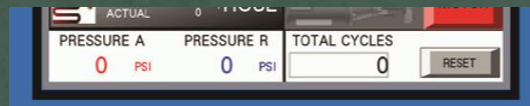
Graco retrofit kit assembly

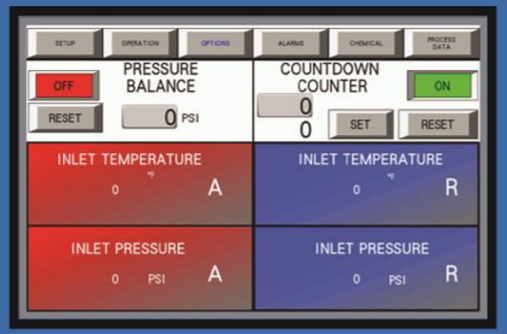
"Prevent, Detect, and Monitor Off-Ratio Conditions"

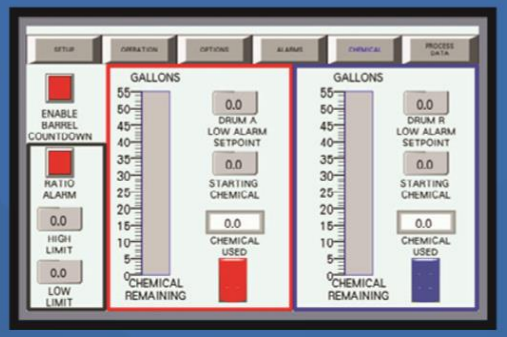
PMC PHDX-2

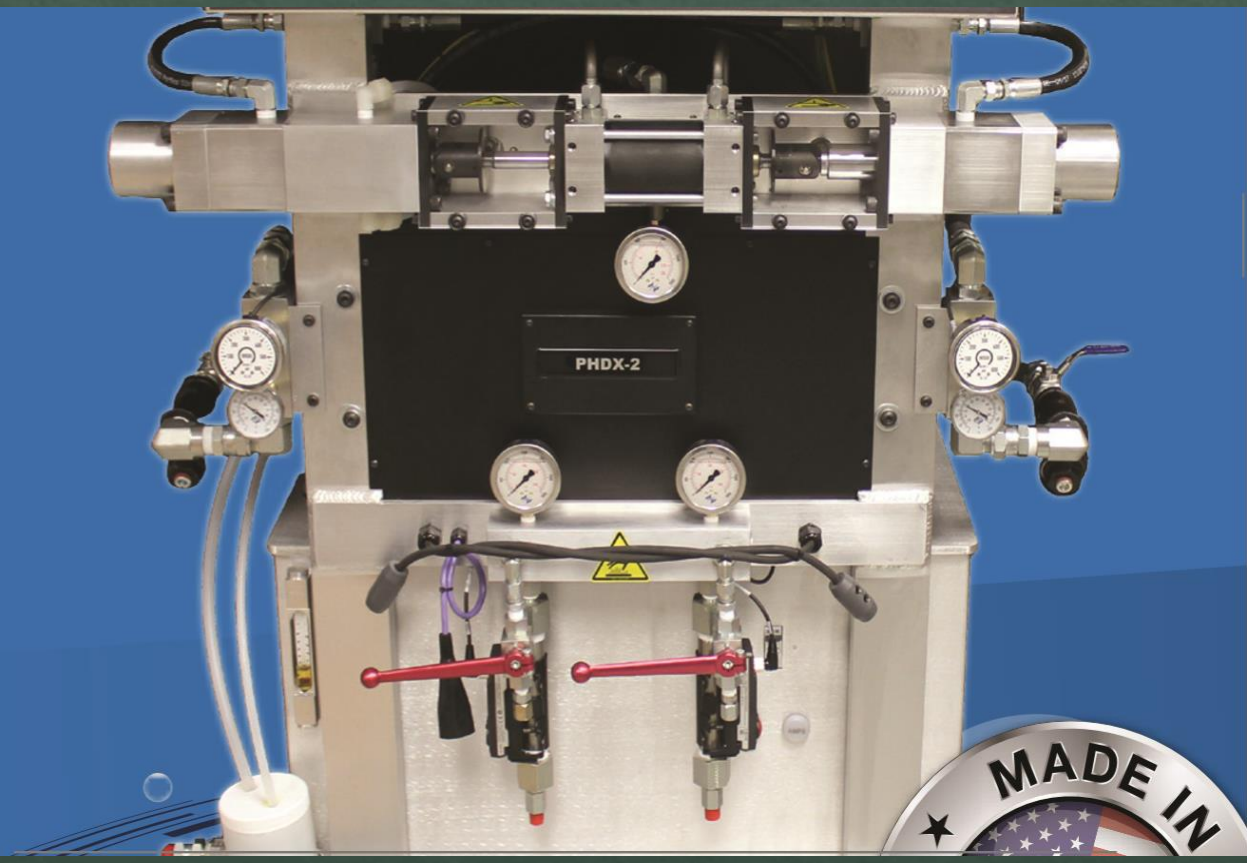
Smart Machine PHD/PHDX-2 Series

Foam and Coatings Proportioners









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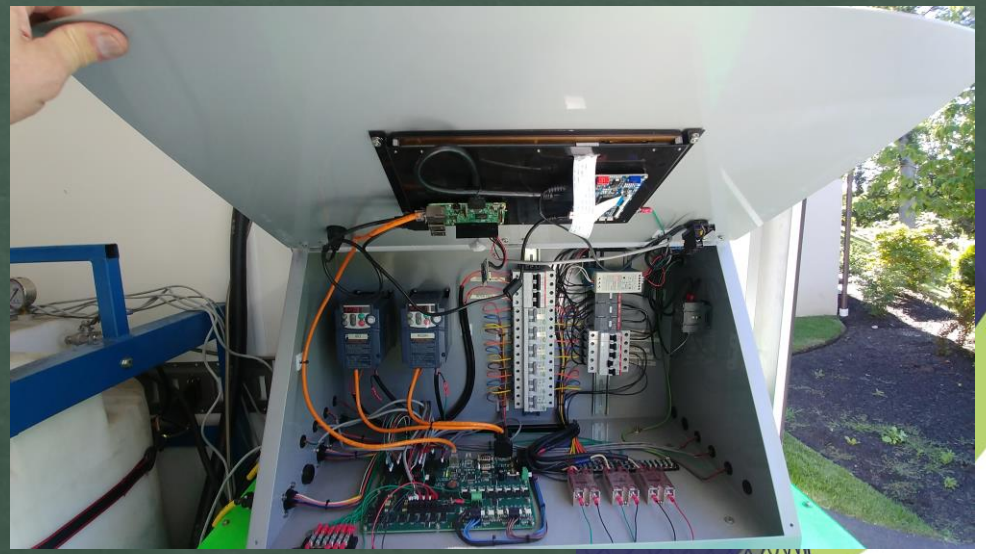
Akurate Dynamics Delta CPS



The All Around Best System

Akurate Dynamics innovators solved a chemical processing problem to create the best spray foam chemical processing system in the industry, providing consistent, high quality results and an excellent return on investment.

Our technology is not the previously used piston pump technology nor did we simply build a new reactor. Instead, our system is a total innovation of spray foam chemical handling, processing, application, and reporting.

Take a look at the future of spray foam technology with Akurate Dynamics.

Innovation with Purpose

Akurate Dynamics Delta CPS™* is the next generation in chemical processing systems designed for the spray foam industry. We specifically designed this system to address the most important aspects in the application of plural component polyurethanes and polyureas. Our engineering and manufacturing teams design and produce all spray foam equipment in-house, and our innovations enable and ensure the following benefits:

- Ease of Use & Application
- Safe & Efficient Chemical Handling
- All Work Aligned with Manufacturer Specifications
- Automated On-Ratio Spraying
- Enterprise Reporting
- System Reliability & Ease of Maintenance
- Customer Satisfaction
- Increased Profitability
- Designed for Regulatory Compliance

* Patent Pending

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Akurate manual calibration

Fault-protection processing monitors

Ratio monitor products	Yes per product	Can be retrofit	Reports supply chemical temps. in the drums/ tanks (degrees F)	Transfer rate (GPM/PSI)	Temperature at proportioner inlet (degrees F)	A-B pressure difference (PSI)	Shows instantaneous flow (#/min)	Shows total flow (pounds)	Shows flow ratio (A to B)	Temperature at proportioner output (degrees F)	Shows temperature at the gun (degrees F)	Fault protection for all process parameters	Generates a processing parameter report
Industry-standard machines (1950)	3+	N/A	No	No	Yes	Yes	No	No	No	Yes	No	No	Partial
Akurate Dynamics Delta CPS	9-	No	Yes	No	Yes	Yes	Yes	Yes	Delayed	Yes	No	Delayed	Yes
Graco Reactor 2 Ratio Assurance system	9+	Some Models	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Polyurethane Machinery Corp.	8	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
PFPI ratio monitor (1995)	9	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
(Critical parameters)	No	Yes											

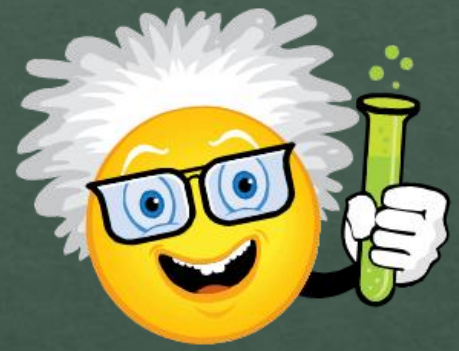
Fault-protection processing monitors

- These systems require a tolerance for proper processing
- The standard ratio for the industry is 1:1 or 100:100 by volume
- There are no machines that can process at exactly 1:1, so we need to know where the variance is too high to allow proper processing

Understanding the processing parameters

What does the chemistry require?

SPF is a two-component chemical system that is manufactured on site. It requires:



- Properly conditioned chemicals
- Precise proportioner performance
- Proper delivery of the chemicals from the proportioner to the gun
- A complete chemical reaction of all of the components as the product leaves the gun

Processing parameters Installers have to meet!

Critical processing parameters include:

1. The temperatures, flow rates, and pressures of the supply chemicals **as they are being *delivered to the proportioner***
2. *Proportioning and heating of the supply chemicals* ***at the proportioner***
3. The temperature, flow ratio, and pressures of the proportioned chemicals **as they are being *delivered to the gun (after the proportioner)***

The processing system

The foam industry relies on this equipment to provide processing quality with no feedback about the actual flow ratio

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Courtesy: Graco, Inc.

Where do we get the processing information?

Typical industry documentation:

- Product Data
- Application Guide
- Installation Instructions
- Safety Data Sheets
- Evaluation Service Report
- Marketing documents
  - The data Installers need is typically scattered among these documents and there is no standard for how or where the data is to be presented to the users
  - There may be conflicts! Some documents may be out of date, even the ones on web sites
  - Some products change, but the documentation doesn't always keep up

What processing information do we need? What did the chemists really ask for?

- There should be about 20 Processing parameters provided, not counting the tolerances for each
- Usually, only about half of these are in the documentation
- Usually, foam manufacturers do not provide tolerances for most of these parameters

“At-a-glance" parameter list for use in the field

Twenty process parameters on the checklist

Processing Matrix			
Manufacturer		Conflict	
Product		Missing	
Seasonal formulation		Critical - missing	
Chemical Processing	**Setting/thresholds**		
	Low limit, Min.	**Target**	**High limit, Max.**
A Shipping & storage temperature (F)			
B Shipping & storage temperature (F)			
A Preconditioning temperature (F)			
B Preconditioning temperature (F)			
A Supply inlet temperature (degrees F)			
B Supply inlet temperature (degrees F)			
Recirculation / mixing required			
Transfer rate/pressure to proportioner			
A Pressures (PSI)			
B Pressures (PSI)			
Maximum A-B Pressure difference (PSI)			
Flow ratio (by volume)			
A Specific gravity			
B Specific gravity			
A Temperature at pump (degrees F)			
B Temperature at pump (degrees F)			
Temperature in hoses (degrees F)			
Temperature at gun (degrees F)			
Reactivity profile (seconds)			
Length of cure period (hours)			
Others (list here):			

The Automatic (FPM) Quality Control Option

- Process monitoring equipment can verify that all process parameters are being met full time
  - Eliminates expensive manual verification
  - Automatically records processing data
- Can provide a warning to the Installer before material quality is compromised (FPM system presets)
- Provides automatic fault-protection shutdown
- Provides proof-of-QA/QC reporting

Processing Parameters by method	Manual vs. Automatic verification			FPM triggers automatic shut down
	Manual verification only	Classic machine controls	FPM reporting	
A - Shipping & storage temperature (F)	X	X - Off site		
B - Shipping & storage temperature (F)	X			
Recirculation - required or prohibited	X	X	X	X
Mixing - Adequate or prohibited	X	X	X	X
A - Supply chemical temp. (F)			Coming soon	
B - Supply chemical temp. (F)				
A - Proportioner inlet temp. (degrees F)	X	X	X	X
B - Proportioner inlet temp. (degrees F)	X	X	X	X
Transfer rate/pressure to proportioner			X	X
A - Pressures (PSI)	X	X	X	X
B - Pressures (PSI)	X	X	X	X
A-B pressure difference (PSI)	X	X	X	X
Flow ratio (by volume)			X	X
A - Temperature at proportioner (degrees F)	X	X	X	X
B - Temperature at proportioner (degrees F)	X	X	X	X
Temperature in the hoses (degrees F)	X	Sometimes	X	X
Temperature at the gun (degrees F)			X	X
Length of cure period (hours)	X	X	X	X
Test shot quality	X	X	X	X

X = manual, Pink = Critical feedback not provided, Green = Critical feedback & control provided

Industry-standard QC

"spray out a small amount of material to verify the quality of the SPF produced."

Quality control (Testing)

SFC "Guidance on Best Practices for the Installation of Spray Polyurethane Foam“

4.1) Applying and Processing Spray Foam on the Jobsite

Verify the Jobsite: On the day of application, verify and review all the items discussed in Section 3.

Ambient and Substrate conditions: Prior to actual application, review the ambient/atmospheric and substrate conditions for the parameters recommended by the SPF manufacturer. The manufacturer's technical data sheet or guidelines have the parameters associated with the ambient conditions.

Temperature and Recirculation of Material: Comply with the manufacturer's guidelines for the preparation and processing of the SPF component materials. Manufacturers may recommend recirculation of the polyol material and some may recommend recirculation with heating. Follow the manufacturer's instructions closely.

SPF Quality Testing: Prior to starting the day's spraying operations, spray out a small amount of material to verify the quality of the SPF produced. Use caution when spraying test buns and allow the buns to have an opportunity to properly cool before disposing of them. Use extra caution if spraying SPF test buns into plastic bags because it can reach the point of spontaneous combustion and could cause a fire. Disposal is also important and lack of attention to the disposal of scrap SPF can cause a fire.

Thickness of Application: Follow the SPF manufacturer's recommendations concerning the thickness of individual passes (lifts) and the cooling time between passes. Applying too much SPF per pass, without allowing time for the foam to cool, could cause poor foam quality and create a fire hazard resulting from too much heat from the reaction and spontaneous combustion. Closed cell

Quality Control for the processed product

Manual methods for determining if parameters are being met **at the gun**

1. Confirm the material temperature at the gun
2. Use test shots to verify that the chemicals are completely mixed and reacted
   - Verify strip tests sprayed within the maximum pass thickness
     - Do not spray side-to-side or overlap the pass – make one straight spray line
     - Check the “surf board’s” color, cell shape and color uniformity, texture uniformity, odor, “snap,” etc.

“Surfboard” strip tests

“Surfboard” strip tests

Always do test shots before starting the installation

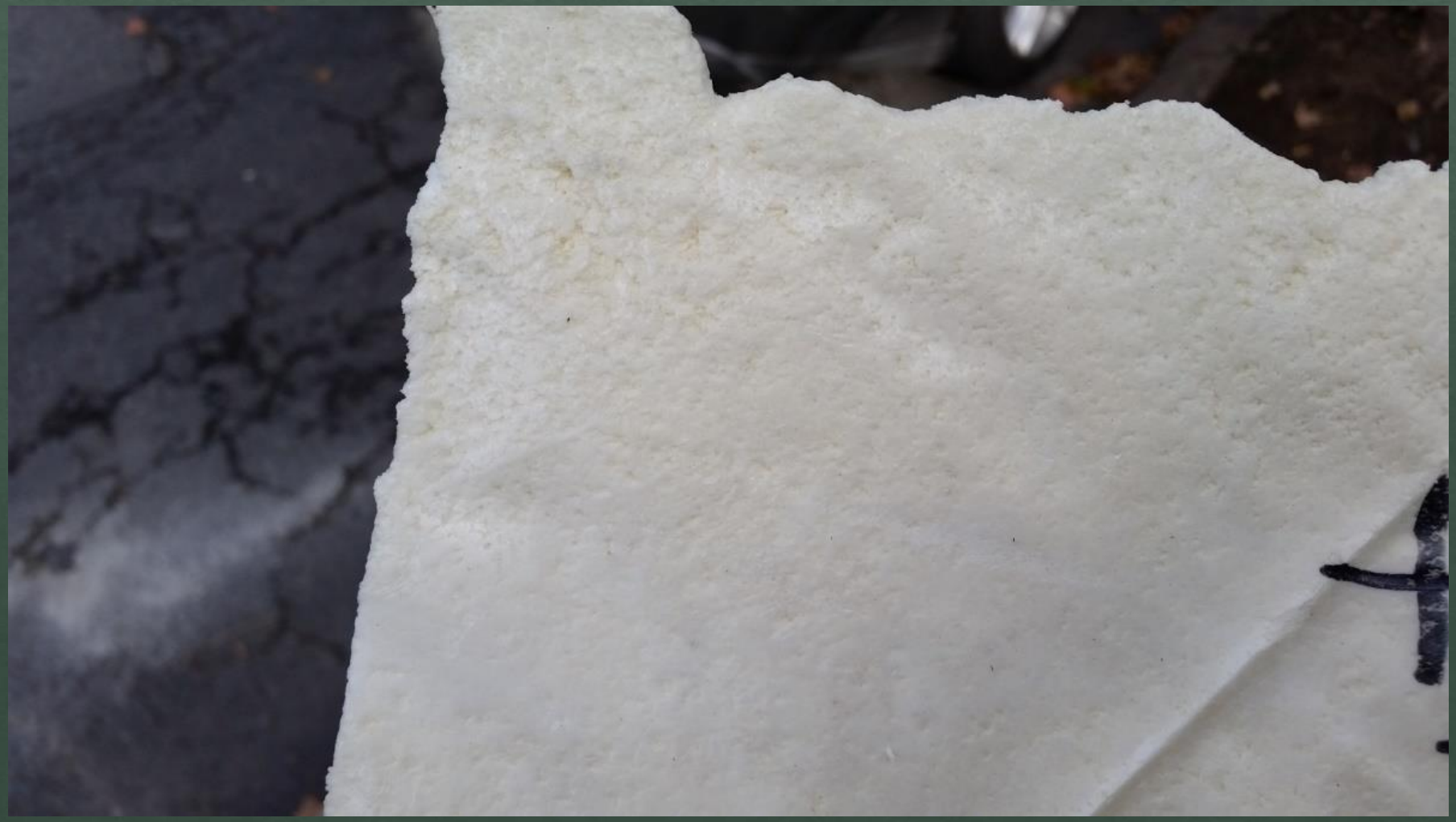
“Surfboard” strip tests

Label these and take photos of the strip tests as proof of quality.

Remember not to spray in the normal back-and-forth pattern when doing a strip test.

“Surfboard” strip tests

Variations in color, cell size, and texture show inadequate temperature or mix. The textured area in this photo was friable and easily broken.



“Surfboard” strip tests

Always do test shots before starting the installation, if for no other reason than to clear the cold material from the whip. This type of material could put the entire project’s quality in question.

Strip tests can show lead and lag, poor mix, and cold material.

“Surfboard” strip tests

Color, texture, and cell shape variations indicate unmixed, unreacted, or off-ratio chemicals.

“Surfboard” strip tests

Cut cross-sections and confirm cell size and shape, and color uniformity

“Surfboard” strip tests

How do we assure installed product quality?

Create standards that require:

- Foam manufacturers to provide a complete set of processing parameters including tolerances
- Installers to measure the temperature of the supply chemicals if FPM systems don’t
- Installers to use fault-protection process monitoring systems (FPM systems)
- Installers to perform test shots and report results
- Installers to report manual parameter verification for any parameters that FPM systems don’t address

How do we assure installed product quality?

Specify the following:

- Require foam manufacturers to submit a complete set of processing parameters including tolerances
- Require installers to measure the temperature of the supply chemicals if the FPM systems doesn’t
- Require installers to use fault-protection process monitoring systems (FPM systems)
- Perform and report test shot results
- Require the installer to report manual parameter verification for any parameters that FPM monitors don't address

How do we assure installed product quality?

Require a foam commissioning agent to:

- Confirm that the foam manufacturers provide a complete set of processing parameters, including tolerances
- Verify the temperature of the supply chemicals
- Inspect and report test shot results
- Report manual parameter verification for all processing and installation parameters

Processing QA for Spray-applied Polyurethane Foam – New Equipment and Test Shot Method

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Thank you for your time!

QUESTIONS??

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