Development and Implementation of an Automatic Continuous Online Monitoring and Control Platform for Polymerization Reactions to Sharply Boost Energy and Resource Efficiency in Polymer Manufacturing

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Project Objective

What we are trying to do: **Fully automate the manufacturing of polymers, a large portion of the vast U.S. chemical manufacturing industry , thus making more efficient use of energy, non-renewable resources, time, and labor**

What is the problem? **To develop a technology for both automatically monitoring and controlling chemical polymerization reactions.**

Why it is difficult. **Despite decades of manufacturing there is currently no well established online method for continuous monitoring and control of polymerization reactions, because the nature of the reactions is very complex and the characterization of polymers is a large challenge even when carried out off-line on manual harvested samples.**

The U.S. Chemical Industry; an energy intensive sector

Technical Innovation

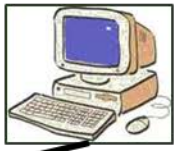
How it's Done Now

Reactor

QC Lab

$Ms in Waste & inefficiency: long delay in measurement

Failed R. Control

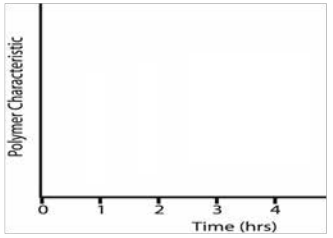


Plant Control System

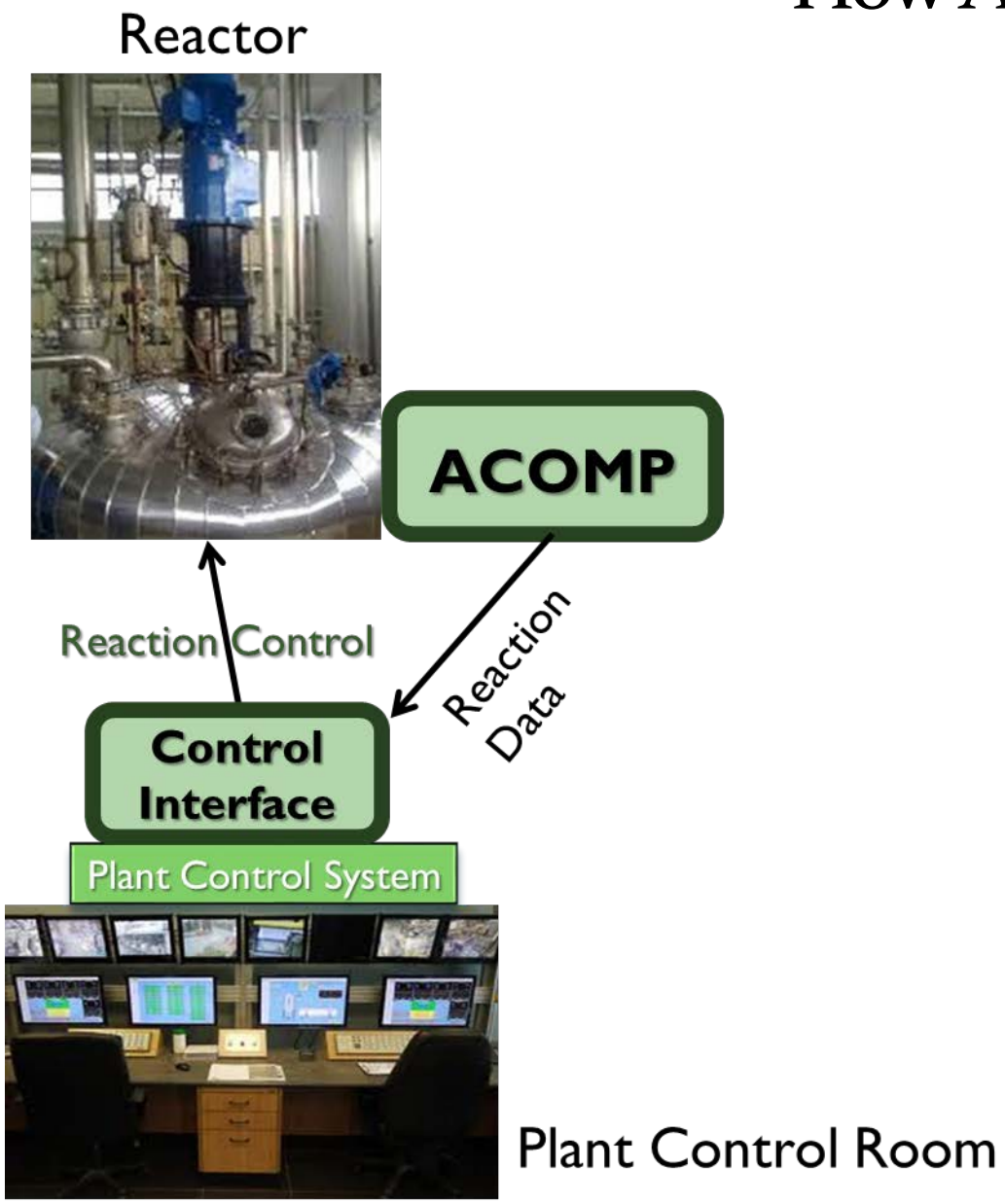
Operator Control

Reaction Data

Plant Control Room



How ACOMP/CI Works



Value to Users

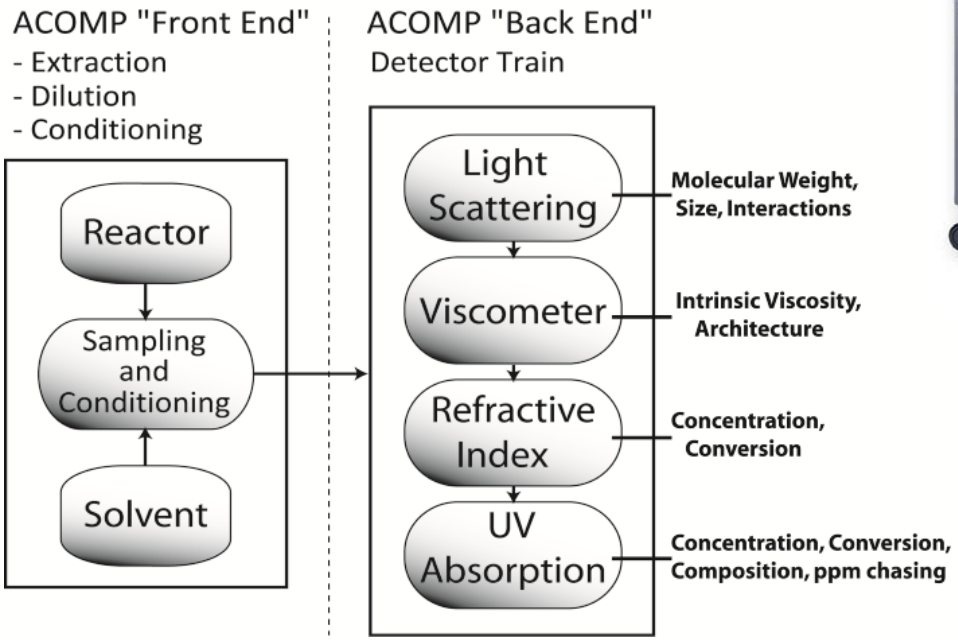
- ✓ Cost-savings
- ✓ Yield increase
- ✓ Reduced energy use
- ✓ Improved product quality
- ✓ Enhanced sustainability (reduced GHG emissions)
- ✓ Increased worker safety

Automated Feedback Control

Technical Approach

- Automatic Continuous Online Monitoring of Polymerization reactions combined with a Control Interface: ACOMP/CI: Continuously automatically measure and control all relevant characteristics of polymerization reactions
- ACOMP invented and developed at Tulane. Patents exclusively licensed to APMT, Inc.

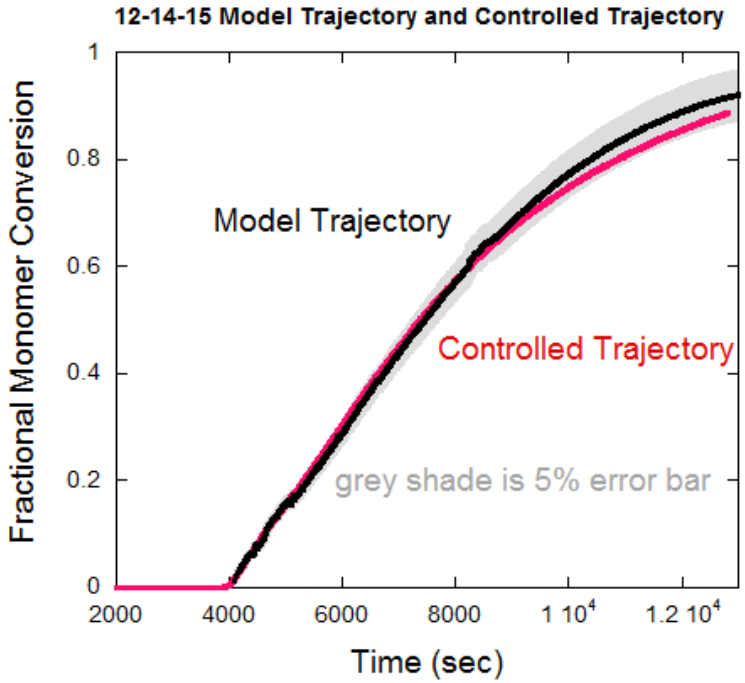
1st industrial ACOMP (no CI) deployed 10/14 by APMT

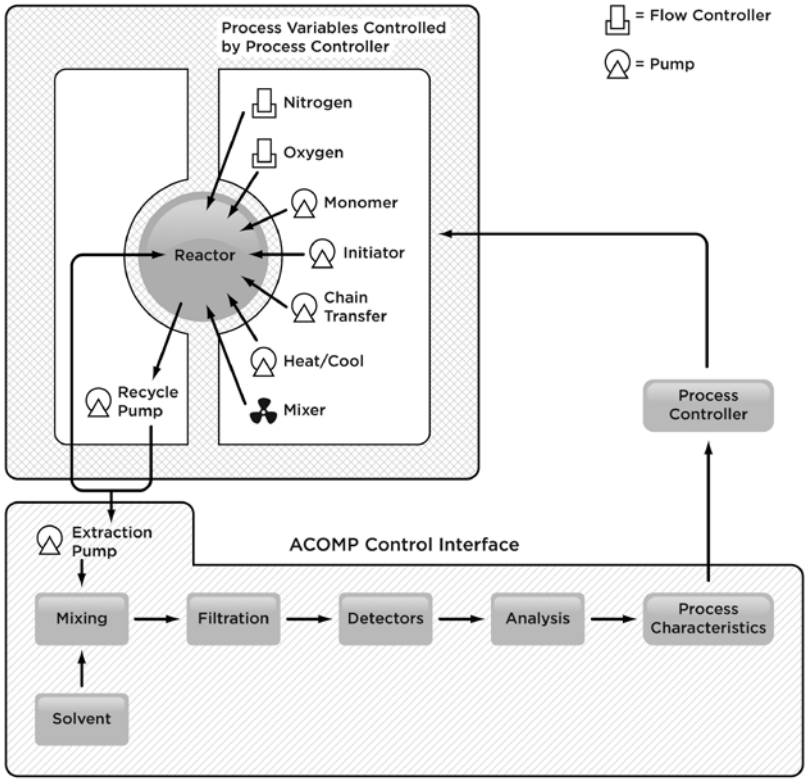


2nd industrial ACOMP (no CI) deployed 5/16 by APMT

Technical Approach

- ACOMP's unique ability to continuously monitor polymer molecular weight, composition, kinetics , and other reaction characteristics gives it unprecedented opportunity for ***reaction control***
- APMT has built first ACOMP/CI to allow development of reaction control: i) Tulane/APMT is pioneering model-free control. ii) LSU group working on model-based non-linear control
- **CENTRAL IDEA: Following a pre-determined reaction trajectory automatically will lead to exactly the right polymer every time**





Reactor control variables: monomers, T, initiator, CTA, etc.

Transition and Deployment- Why it's Important

- ***End users are potentially all polymer manufacturers***
- Chemical industry supports nearly 25% of U.S. GDP (supports manufacturing in autos, heavy equipment, aerospace, etc.)*
- Est. $250 B in U.S. shipments in 2013 (subset of $812 B US Chemical manufacturing industry)*
- Direct+indir. employment for entire chemical industry= 6M+*
- Average pay for all chemical industry workers: $88,800*
- Chemical industry is 2nd largest consumer of all U.S. manufacturing energy at 24.4%**
- Annual consumption 2,700 Trillion Btus equivalent to 470 million barrels of crude oil**

*From American Chemistry Council research
** From DoE-EIA energy consumption and industry emissions surveys

Polymers are used in many manufacturing sectors

Transition and Deployment

- End-user: small, medium and large polymer manufacturers
  - Manufacturers will purchase and operate monitoring and control platform
  - The platform will improve energy and feedstock efficiency, yield, profitability and product quality of polymer production processes
- Commercialization Approach
  - Start-up (APMT, Inc.) has exclusive license to IP from Tulane and has also filed multiple new patents
  - Partnerships with instrumentation and automation companies have been developed to prepare to scale
  - Validation of monitoring technology (**w/out predictive control**) at industrial scale - 17% reduction in cycle time; 2nd unit installed 5/2016
- Capital equipment & service model coupled w/SaaS sales model for any software modeling and data analytics features

Measure of Success

With automated feedback control of polymerization reactions, the team expects:

- Reduction of batch cycle and grade changeover time, off-spec production, unexpected production events
- Reduced energy and feedstock consumption per lb. of polymer produced
- Success measured by comparison of production performance before and after adoption of the platform
- Economic impact- annual cost savings and added capacity valued at $Millions per reactor (1,000+ reactors in U.S.)

Annual savings per year due to 1% reduction in off-specification product from online polymer monitoring of one U.S. plastic industry Sector: polyethylene, polypropylene, polystyrene, PVC

Annual Production (million tons/year)	38.38
Energy savings (million Barrels of Oil/year)	4.33
Green house gas savings (million tons/year)	2.99
SO2 Savings (million tons/year)	0.59
Monetary savings (million $/year, zero profit environment)	$ 388.13

Source: Emma Wilson, Tulane

Annual production data : Plastics Industry Producers' Statistics Group, Vault Consulting, LLC; ACC © April 2016 American Chemistry Council, Inc.
Energy data from Franklin Associates: Cradle-to-gate life cycle inventory of nine plastic resins and four polyurethane precursors, 2011
Pollution data from life cycle assessment literature review. Monetary data: spot price Nexant, Bloomberg

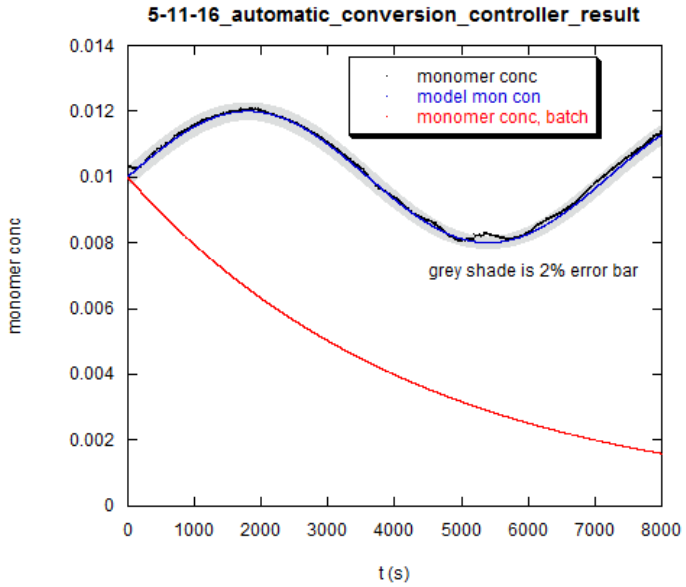
Project Management & Budget

- 2 year project 12/24/14-12/23/16
- Milestone 2 (go/no-go): Pilot scale demonstration utilizing new ACOMP/CI and active manual control of batch polyacrylamide reaction- **achieved 12/22/15**
- Milestone 3: Fully automatic control of molecular weight during polymerization- **achieved 5/14/16**
- Milestone 4: Extension to industrial type reactions: **beginning 7/1/16 until 12/23/2016**
- Milestone 5: Extended control strategies, including model-based non-linear approaches: **beginning 7/1/16 until 12/23/2016**

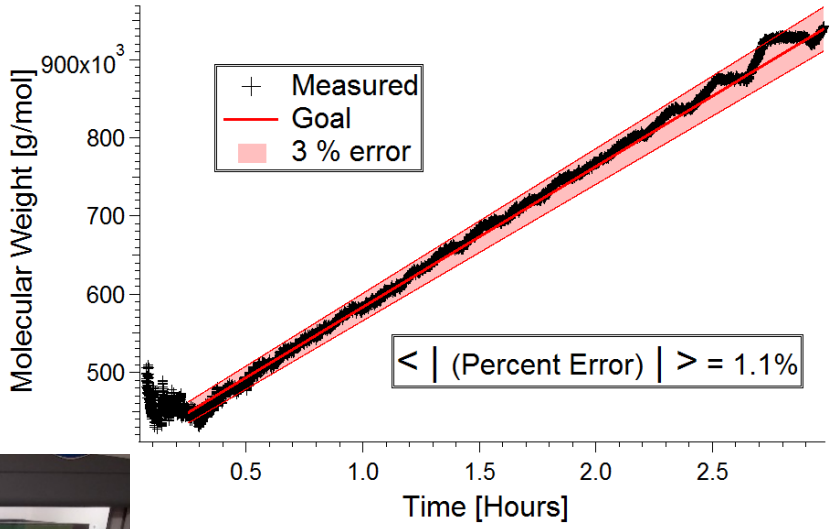
Total Project Budget	
DOE Investment	$1,500,000
Cost Share	$376,452
Project Total	$1,876,452

Results and Accomplishments

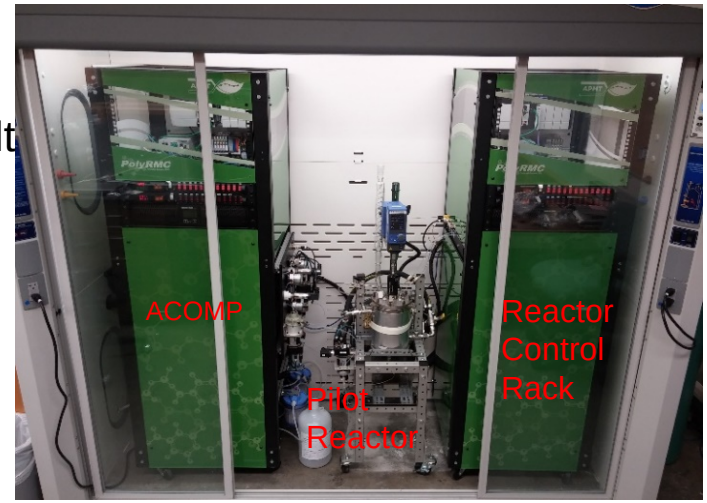
Automatic feedback control of polymer production



First ever automatic feedback control of molecular weight during polymerization



ACOMP/CI built by APMT, Inc
Commissioned July 2015



Until 12/23/2016:

- Extension to copolymerization and more complex reactions
- Advanced controller development
- Kindling commercial interest