Development and Implementation of an Automatic Continuous Online Monitoring and Control Platform for Polymerization Reactions

DE-EE0005776

Tulane University (Prime), Louisiana State University, Fluence Analytics

12/24/2014-12/31/2016
no cost extension 1/1-6/23/17

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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**

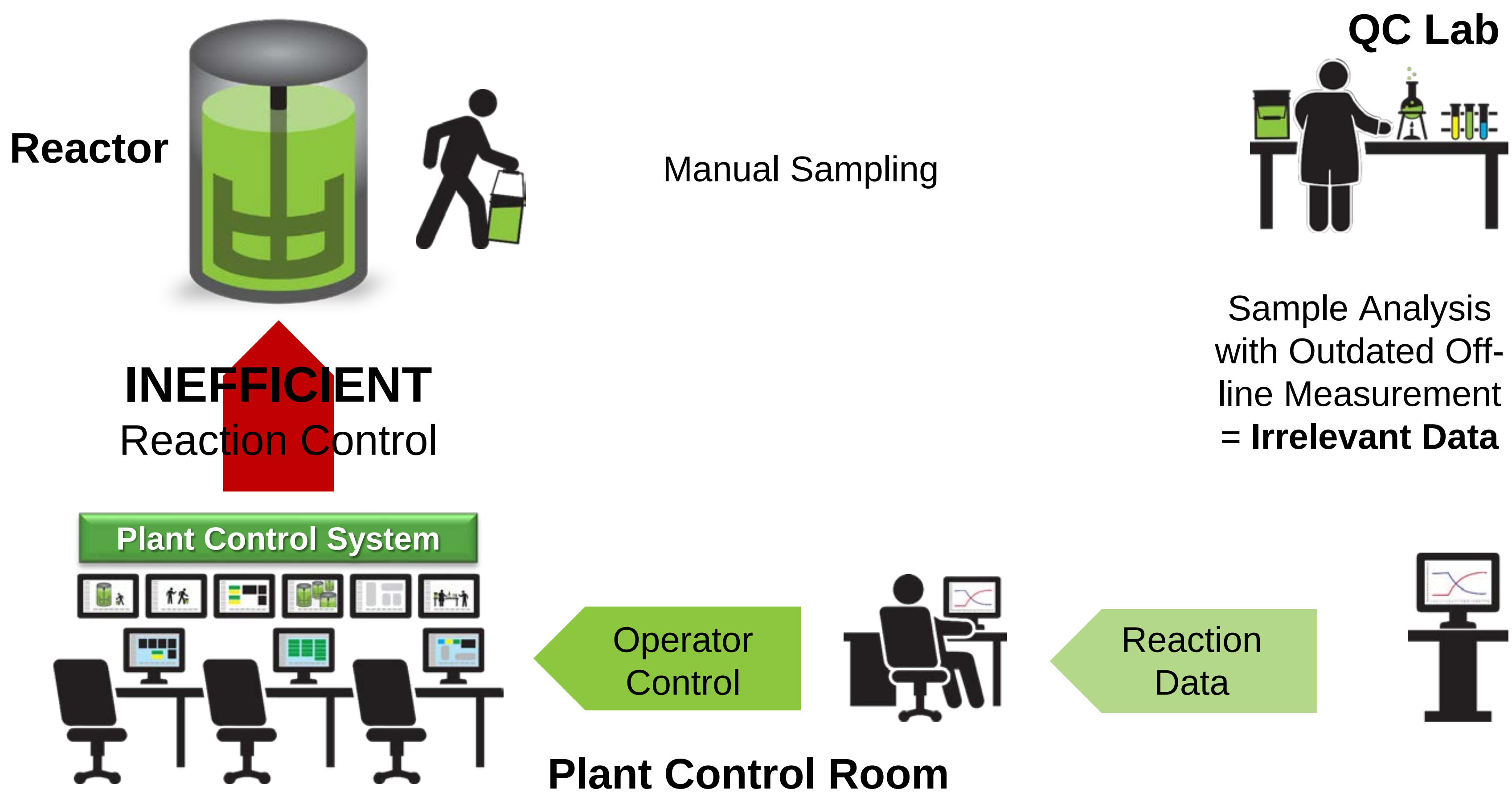
What is the problem? **To develop a technology for both automatically monitoring and controlling chemical polymerization reactions.**

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.**

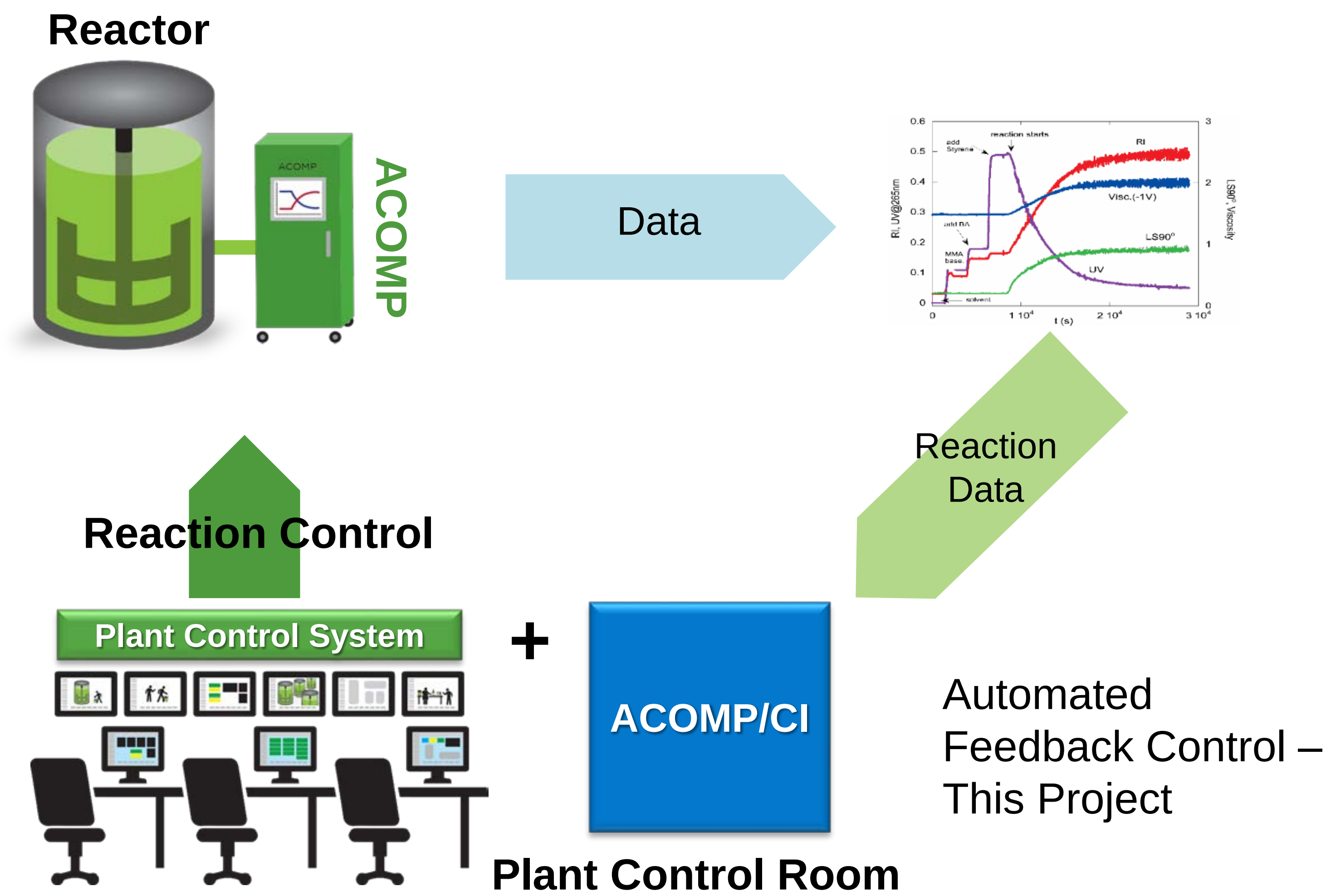
The U.S. Chemical Industry; an energy intensive sector

Technical Innovation

How it's Done Now



How ACOMP/CI Will Work



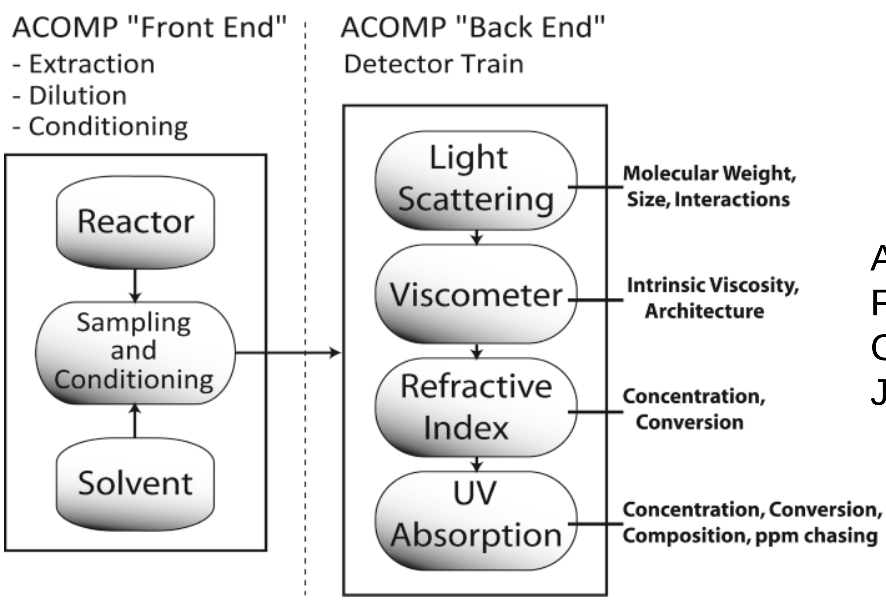
Technical Approach

- 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 Fluence Analytics (formerly APMT, Inc.)

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

2nd industrial ACOMP (**no CI**) 8/16 by APMT

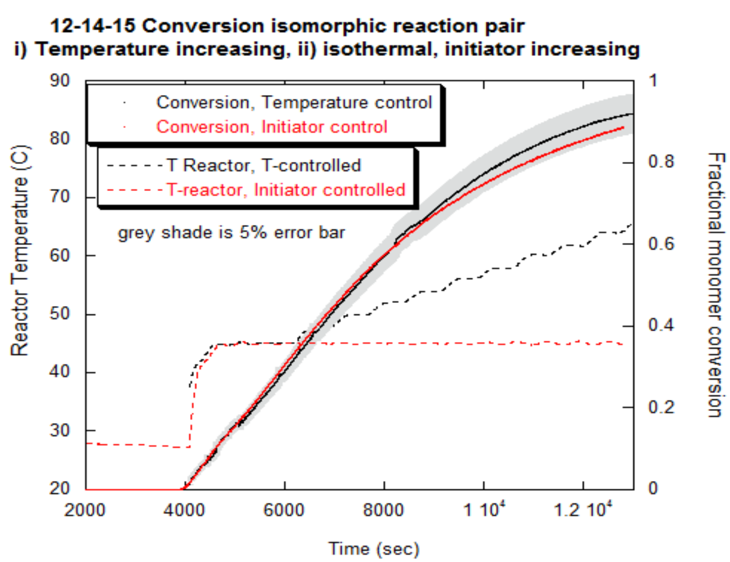


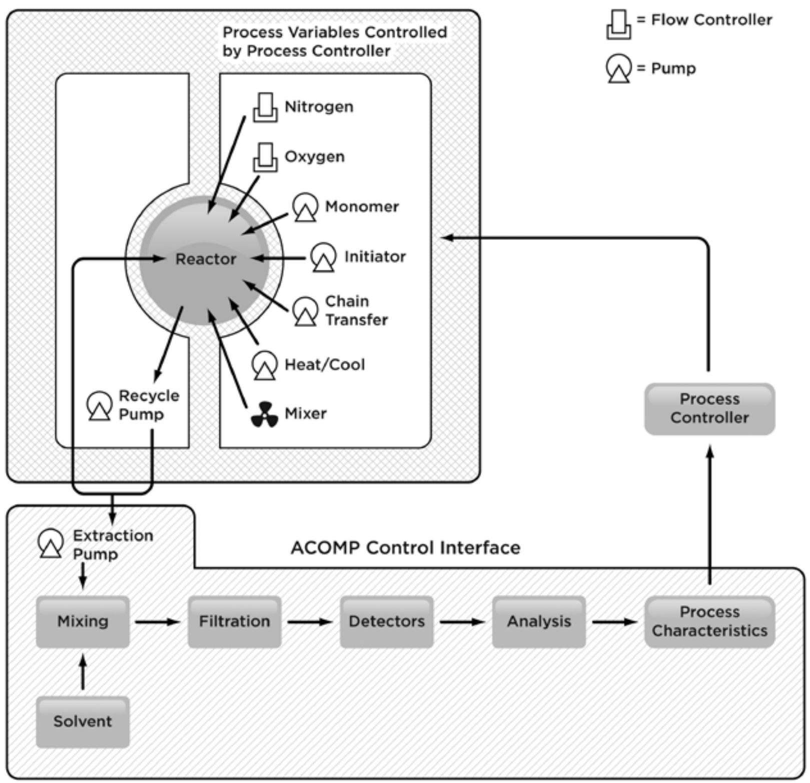
ACOMP/CI built by Fluence Analytics Commissioned July 2015

Technical Approach

- ACOMP's unique ability to continuously monitor polymer molecular weight, composition, kinetics, and other reaction characteristics gives 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 (beyond DOE assistance) - 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

Transition (beyond DOE assistance)

- End-users are polymer manufacturers
  - Manufacturers will purchase base monitoring product
  - **Applications development and R&D required to adapt ACOMP to additional processes**
  - ACOMP/CI software will be developed and sold as 'add-on' package to base ACOMP units
  - The platform will improve energy and feedstock efficiency, yield, profitability and product quality of polymer production processes
- Commercialization Approach
  - Start-up (Fluence Analytics) has exclusive license to IP from Tulane and has also filed multiple new patents
  - Partnerships with suppliers, instrumentation and automation companies have been developed to prepare to scale
  - Validation of monitoring technology (**<u>w/out predictive control</u>**) at industrial scale - 17% reduction in cycle time; 2^{nd} unit installed 8/2016
- Capital equipment & service model coupled **w/Platform as a Service (PaaS)** 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 (TBTu/year)	65
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 Johnson, 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

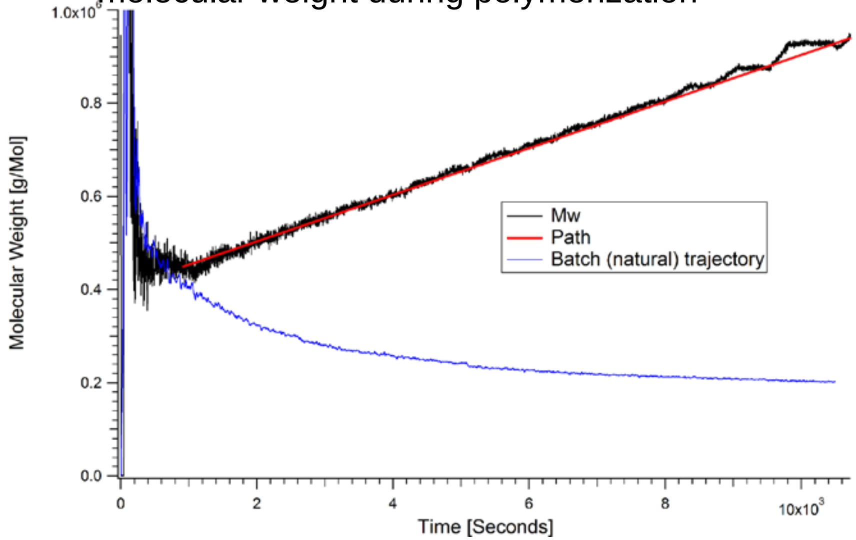
Project Management & Budget

- 2 year project 12/24/14-12/23/16, with no cost extension 1/1/17-6/23/17
- 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 6/23/2017**
- Milestone 5: Extended control strategies, including model-based non-linear approaches: **beginning 7/1/16 until 6/23/2017**

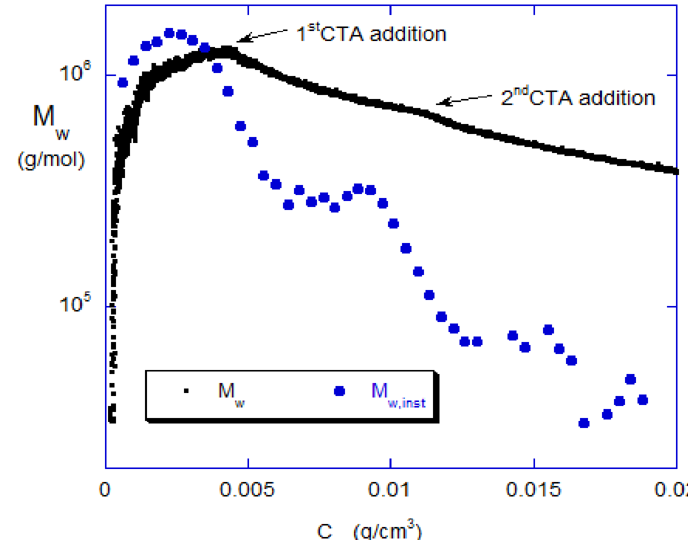
Total Project Budget	
DOE Investment	$1,500,000
Cost Share	$376,452
Project Total	$1,876,452

Results and Accomplishments

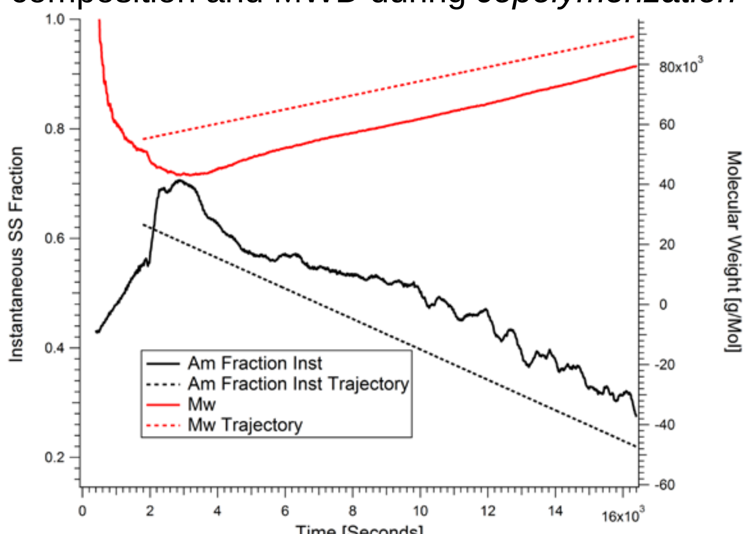
First ever automatic feedback control of molecular weight during polymerization



Fully automatic production of a tri-modal molecular weight distribution during polymerization



First ever automatic *SIMULTANEOUS* control of composition and MWD during *copolymerization*



First coupling of NMR to ACOMP; monitroing terpolymerization