Energy Management in Polymer Processing

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Sustainable Thermal Energy Management in the Process Industries International Conference (SusTEM2011)
Energy management in polymer processing

• EPSRC funder collaboration between Queen’s University Belfast & University of Bradford

• Started April 2010
The aim of the project is to develop methods and technologies to facilitate the efficient use of energy in existing polymer plant operation and in the design of future processing plants.

• Develop an energy management tool for polymer processing

• Develop monitoring and control techniques to optimise energy use and quality in extrusion

• Validate 1 and 2 under industrial conditions

• Disseminate results widely to the UK polymer processing industry in the first instance and then internationally.
Work Programmes

• WP1: Energy management tool: development and validation (QUB)

• WP2: Application of novel process monitoring techniques and determination of effect of processing/material on specific energy consumption in extrusion (Bradford)

• WP3: On-line monitoring and control (QUB)
Presentation outline

• Project overview & description of Energy Management Tool: Eileen Harkin-Jones

• Development of enhanced extrusion control: Jing Deng
Background

- UK is one of top 5 plastics processing countries in Europe
- Turnover £19 billion equivalent to 2.1% of GDP
- Very energy intensive processes
- Typical electricity bill is 3-5% turnover (£380 million p.a in UK) but also big users of gas
- Mainly SMEs (7400 in UK) who don’t have the capability to tackle the problem individually
Typical process involves:

- Material drying and conveying
- Melting/mixing
- Forming-die/mould
- Cooling
- Cutting
Background

- 90% of polymer processing methods involve an extruder
- The extruder typically accounts for 50% of total process energy so key area to focus on
Extrusion has high energy consumption per kg of product due to:

- Long set up/change over times during which waste product is produced [energy, material, productivity losses]
- Poor response times to process disturbances leading to off-spec product
- Operated with unsuitable screw geometries resulting in inefficient processing
- Lack of understanding of influence of processing parameters on energy consumption
- Machines run at conservative rates leading to poor specific energy consumption
Background

Apart from the extruder there are many other areas where energy may be saved

- Polymer drying – dryer efficiency could be increased from 35% to 55% by recovering heat from exhaust gases
- Compressed air used in all polymer processing plants – 10 times the cost of electricity at point of delivery – major opportunities to minimise demand and optimise supply
- Many opportunities to make use of low grade heat lost at various points in the processing lines
The challenge

- Company will devote far more effort to increasing sales or productivity than it will to reducing energy costs

- Energy costs are viewed as fixed – necessary evil

- A *culture change* is required before we see real improvements in energy efficiency
The specification for the Energy Management Tool (EMT) has been drawn up in collaboration with industrial partners in order to ensure that what we produce is relevant and will actually be used [user friendly and showing clear benefits to company]

We have initiated a number of partnerships with local polymer processors to see how energy management is currently being implemented

A case study will be presented to give an idea of how the industry is operating at the moment
Company case study

- In house extrusion, thermoforming and printing of packaging
- 24 hour operation
- 200 employees
- £20-25 million turnover
- Forward thinking and invests in new technologies
- Energy manager and energy policy
The thermoforming process

- Sheet material extruded
- Fed to thermoformer
- Skeletal waste ground up and fed back to extruder
- Not considered as waste material because it is recycled but energy to process not considered!
Results from preliminary visits

- When thermoformer is off for a roll changeover or maintenance the sheet heaters, granulator and blowers are not switched off.

- Fans on printers not switched off when printer not running.

- Heaters and pumps for the calendar rolls on extruder kept on when machine off for material change/minor maintenance
Machine ratings

**Formers (PFs):**
Granulator (32kW – 5.5kW) and Blower (6kW - 2.2kW);
Pre-heating Equipment (9kW - 32kW), where applicable;
Main heaters (94.5kW - 20.35kW).

**Extruders (EXs):**
Gear Oil Cooling Pump (0.48kW);
Calendar Cooling Pumps (4kW×3);
Calendar Heating Units (12.2kW×3).

**Printers (PPs):**
Extractor Motor (1.5kW);
Machine ratings

Bottler (BL1):

Tool Temperature \((12.9\, \text{kW} \times 2 + 4\, \text{kW} \times 2)\);

Oven Heater \((50\, \text{kW})\);

Granulator \((55\, \text{kW})\) and Blower\((4\, \text{kW})\)
No load current

Granulators = 0.33 (no load current is a third of full load current)

Gear Oil Pump/Calendar Pump = 1.0 (full load operation)

Heaters = 0.2

Extractor for PPs = 1.0 (Full Load Operation)
Costing

- Machine downtime records for 1 year
- Worked out idling time for all ancillary equipment
- Cost of machine idling = idling time x unit cost electricity x no load current factor
<table>
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<tr>
<th>Cost Factor</th>
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<th>Estimated Total Cost of Energy Wasted for All PF Machines in '09</th>
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<td>GranulatorBlower</td>
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<td></td>
</tr>
<tr>
<td>CostFactor</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>OtherCostFactor</td>
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Assuming the Equipment were switched off for 10% of the total down time,
the new reduced estimate of the total cost of wasted Energy for PFs in '09

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<td>CalHeatCostFactor</td>
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<tr>
<td>CalPumpCostFactor</td>
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Assuming the Equipment were switched off for 10% of the total down time,
the new reduced estimate of the total cost of wasted Energy for EXs in '09

<table>
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<th>Factor</th>
<th>Estimated Total Cost of Energy Wasted by All Printing M/cs in '09</th>
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<td>ExtrMotorcostFactor</td>
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Assuming the Equipment were switched off for 5% of the total down time,
the new reduced estimate of the total cost of wasted Energy for PPs in '09

Assuming the machine was switched off for 10% of the total down time,
the new reduced estimate of the total cost of wasted Energy for BL1 in 2009 is

**Grand Total Cost**

£118,215
Potential savings

• This £118,000 could be saved by simply linking the ancillary equipment to main machine motors so that when main machine is off so also is ancillary equipment

• £118,000 is equivalent to more that £2.36 million in new sales if company operating at 5% profit margin

• Figures like this required to convert managers to the importance of energy management
Further unaccounted for costs

- Under no-load, motors have a Power Factor as low as 0.1 to a Maximum of 0.2. Hence, the capacitor banks are overworked.

- Increased breakdowns and maintenance costs for machines running when they don’t need to.

- Continuous load on the shop floor Cooling System (chiller and fans).
Conclusions from company case studies

- Even in companies with energy managers/policies there is huge scope for savings
- Must convert energy loss into £s to get management to act
- Limited staff resource in most SMEs so we need to develop something that is not going to need large human resource to implement
Energy Management Tool (EMT) specification

Level 1
‘In house consultant’

Level 2
SPC
Level 1

- Designed to allow processor to quickly identify areas for energy savings ‘low hanging fruit’

- Guide to reducing energy wastage in polymer processing: Videos showing factory ‘walk about’ and pointing out all areas for improvement and suggesting possible solutions

- Powerpoint presentations on good energy management practices

- Factory layout planning to minimise energy usage e.g layout to minimise piping losses, effect of replacing old m/c etc
• Will integrate freely available energy management and carbon foot printing tools

• Link to Enhanced Capital Allowance list: To be accessed when purchasing new machines
Level 1
Level 2 - SPC

- Power metering is becoming common practice in industry
- Data is not analysed in real time
- Busy managers may not have time to check data by which time may be too late to determine out of control condition
- We are establishing system to record and analyse data in real time using SPC methods
- Establish control chart limits
- Alarm indicates out of control condition immediately
- Can apply to individual machines, total load, power factor
Level 2 - SPC

- Will have a display showing real time energy cost (from level 2) which can be displayed on factory floor and managers offices to raise awareness of cost of energy. Will incorporate graphics showing how energy wastage translates into loss of profit related bonus etc
Level 2
Next step

- Installation of meters and online SPC in local processing company in next month
- Establish control limits
- Assess effectiveness of system in isolating problems [e.g. reduction in motor efficiency, screw wear]
- Populate Level 1 with presentations, videos, machine database, links etc
Development of enhanced extruder control

Dr Jing Deng
Outline

Objectives

Control strategies

Extruder at QUB

Summary

Future work
1. Objectives

- Melt pressure
- Melt temperature
- Feed rate
- Barrel temperature
- Screw speed
- Viscosity

- Melt temperature
- Melt pressure
- Melt viscosity

- Energy usage
- Product quality

control to Optimize
2. Control strategies

Current control

PID control for Barrel temperature settings

PID control for screw speed setting
2. Control strategies

Multi-input and Multi-output extrusion control
2. Control strategies

Challenge 1

High correlation

- Pressure
- Throughput
- Temperature
- Viscosity

High correlation
2. Control strategies

Challenge 2

Viscosity measurement

On-line rheometer

In-line rheometer

Off-line rheometer
2. Control strategies

Challenge 2

Viscosity measurement

Soft-sensor approach
2. Control strategies

- MIMO PID control
- Linear-quadratic regulator (LQR)
- Model predictive control (MPC)

- Fuzzy control
- Neuro-fuzzy control
3. Extruder at QUB

Killion KTS-100 laboratory single-screw extruder

Extruder Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>DC motor power (kW)</td>
<td>2.24</td>
</tr>
<tr>
<td>Screw diameter (mm)</td>
<td>25</td>
</tr>
<tr>
<td>No. of barrel temperature zones</td>
<td>3</td>
</tr>
<tr>
<td>Additional temperature zones connected</td>
<td>3</td>
</tr>
<tr>
<td>Operating speed range (rpm)</td>
<td>0-115</td>
</tr>
</tbody>
</table>

Geometrical screw parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Diameter (mm)</td>
<td>25</td>
</tr>
<tr>
<td>L/D ratio</td>
<td>24:1</td>
</tr>
<tr>
<td>No. of Flights</td>
<td></td>
</tr>
<tr>
<td>Feed Section</td>
<td>8</td>
</tr>
<tr>
<td>Melting section</td>
<td>8</td>
</tr>
<tr>
<td>Melt conveying Section</td>
<td>8</td>
</tr>
<tr>
<td>Apparent compression ratio</td>
<td>3.1:1</td>
</tr>
<tr>
<td>Flight depth in feed section (mm)</td>
<td>4.48</td>
</tr>
<tr>
<td>Flight depth in Melt section (mm)</td>
<td>1.43</td>
</tr>
</tbody>
</table>
3. Extruder at QUB

- Pressure transducer
- Screw speed
- Additional thermocouple
- National instrument Compact FieldPoint cFP-1808
- Power meter
- Ethernet cable
- RS-422 communication
- cFP-TC 120
- cFP-SG 140
- cFO-AI 10
- cFP-AO 210
3. Extruder at QUB

Control interface developed in LabVIEW 2011
4. Future work

- Develop model-based control
- Develop neuro-fuzzy controller
- Optimize energy consumption
- Stability and robustness analysis
- Develop software package
5. Summary

- This work is to improve the energy efficiency and product quality of polymer extrusion process.
- The challenge of extrusion control is to address the correlations of outputs and viscosity measurement.
- Platform, including extruder, real-time data acquisition, and LabVIEW interface have been developed.
- Future work is to develop the extruder intelligent control with adaptive learning abilities.