Scientific Approach to Injection Molding

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What is Scientific Approach to Injection Molding?

- Understanding Science of Injection molding
- Everything substantiated by scientific data
- Scientific approach to establishing molding variables
- Understanding of four critical components
  - Material
  - Part Design
  - Tooling
  - Processing
- Every decision Must be backed by scientific data
Why use Scientific approach?

- Become more efficient
- Cost Savings
- Quality Improvements

Separating from Old Ways

<table>
<thead>
<tr>
<th>Old Ways</th>
<th>To</th>
<th>New Ways</th>
</tr>
</thead>
<tbody>
<tr>
<td>How</td>
<td>How &amp; Why</td>
<td></td>
</tr>
<tr>
<td>Art (sight, sound and touch)</td>
<td>Science</td>
<td></td>
</tr>
<tr>
<td>Myth</td>
<td>Facts</td>
<td></td>
</tr>
<tr>
<td>Jet container approach</td>
<td>TDK approach</td>
<td></td>
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</tbody>
</table>

Decisions based on DATA and DATA only
1980s
Congratulations!
You’ll be head of our operations in the South!
Yowza!

1990s
We’ve got to keep pace...
We’re moving to Mexico.
Ole...

2000s
So... how’s your Chinese?
Gahhhh... Gaggggggh...
What’s One Second Worth?

How about $58,500 per year?

Profit Increases From Cycle Time Savings
300 Ton Machine: Machine Hour rate $/Hr 35.00

Current Cycle Time: 30 seconds

New Cycle time: 29 seconds

Cycle time savings: 2 seconds per minute

Cycle time savings: 2 Minutes per hour

Cycle time savings: (5000 hrs per year) 10,000 Minutes or 166 hours

Total $ amount savings: 166 x 35 = $5810

Total $ amount saved: (10 Machine shop) 58,100

Benjamin Franklin once said “Beware of little expenses; a small leak can sink a great ship.”
### Materials Drying

**Why do we need to dry Plastics Materials?**

All Plastics, when exposed to atmosphere, will pick up moisture to a certain degree depending upon the humidity and type of the polymer.

<table>
<thead>
<tr>
<th>Hygroscopic</th>
<th>Non Hygroscopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymers with high affinity for moisture</td>
<td>Polymers with very little or no affinity for moisture</td>
</tr>
<tr>
<td>Moisture is absorbed into the pellet over time until equilibrium is reached</td>
<td>No absorption of moisture into the pellet. May pick up surface moisture.</td>
</tr>
<tr>
<td>Nylon, ABS</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Polyester</td>
<td>PVC, Polypropylene</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>Acetal</td>
</tr>
<tr>
<td>Desiccant Dryer</td>
<td>Hot Air Dryer</td>
</tr>
</tbody>
</table>
Material Drying Issues

• Too high drying temperature……Discoloration, Property breakdown
• Too long drying time (Over drying)*…..Loss of impact, property breakdown
• Residence time and processing rate
• Hydrolysis…Molecular breakdown
• Materials that Hydrolyze….Nylon, PC, Polyester, Polyurethane, etc..
• Regrind usage and drying
• If you mold hydrolyzable material wet…May as well throw it away

* Rule of Thumb: Resins which pick up moisture fast, also dry fast!
Dew Point meter Vs. Moisture Analyzer

- Measures dryer efficiency
- Easy to calibrate
- Portable
- $800 to $1200

- Measures actual moisture in the material
- Very accurate measurement
- Lab environment/very clean production area
- Preprogrammed material data
- $8000 and up

Important Considerations

- Check incoming resin to cut down on drying time (do you really need 3 hours+ of drying time?)
- Eliminate over drying
- Are you paying for water?
- Dryers are working fine BUT resin is wet??????
Material Mixing, coloring & Loading

• Mixing……Regrind and its adverse effect
• Loss of additives
• Pellet size variations
• Fines
  – Static charge
  – Fast moisture pick up
  – Clogged filters
  – Fast melting
  – Black specks, splay, volatiles, burning…..

NO Hand mixing of regrind…. 

Attaches to grinder
Coloring

- Colorant have pronounced effect on shrinkage
- Organic pigments have significant effect since it tends to interfere with crystallization kinetics and morphological structure of cooling polymer
Loading

Hand Loading
Vacuum Loaders
Pneumatic Loaders
Central Loading
Pressure Loading

Are you also loading moisture?
L/D and Compression Ratio

Compression Ratio

GP Materials 3:1
PVC 1.4:1
Acetal 4:1

Typical Color Master Geometry:
Check Ring Repeatability Study

A. Set up machine to run standard parts
B. Turn off pack and hold time and pressure
C. Make 10 Fill only shots
D. Weigh the parts and record weight
E. Calculate

Acceptable variation is 5% max.
Nozzle Tip Types

Avoid Long Reach Nozzles & tips

- Cold slug
- Burning
- Splay
- Pressure loss
Mold Venting

**Why Vent?**
- Evacuation of latent air that is in the closed mold
- Allow evacuation of gases produced by low molecular weight polymers and additives

**Problems associated with poor venting**
- Burn marks
- Poor mold filling
- Weak weld lines
- Internal bubbles and non-fill areas
- High stress concentration
- Sink marks
- Longer cycle time
- Mold deposit build-up
- Down time

VENT THE RUNNER....

PERIMETER VENTING

YOU CAN’T HAVE TOO MUCH VENTING!!!!!
VENTING

If porous metal pins gets too hot & plugged

Use

Vacuum (Logic Seal) to provide cooling

Venting problems with Delrin acetal resins can be made more obvious by spraying the mold with a hydrocarbon (Rust preventive spray) or Kerosene-based spray just before injection. If venting is poor, hydrocarbon will cause black spot where air is trapped.
Mold Filling Simulation to Optimize Design & solve molding problems

- Optimize gate locations and number of gates
- Confidence of fill
- Knit line and gas entrapment locations
- Fill time
- Pressure distribution
- Temperature distribution
Major Process Variables

- Temperature
- Flow Rate (Injection velocity)
- Pressure
- Time (Cooling)

Interdependence of Variables .......
Temperature

Where does the heat to melt the polymer come from?

External  
Internal

Heater bands  
Screw

Heat Profile settings
Rear  Middle  Front  Adapter/Nozzle

Ascending Profile……small shot size in large barrel
Reverse profile………large shot size in small barrel
Temperature

Melt temperature affects cycle time

**BTU’s (heat) IN = BTU’s (heat) OUT**

Heat always travels from HOT to COLD at a given rate based on each materials rate of transmission or thermal diffusivity

Some materials give off heat faster than others……..

Parts Must be cooled below Heat Distortion Temperature (HDT) of the Plastics in order to eject it out of the mold without warpage

The Hotter the melt…..Longer the cooling time

Avoid too high or too low Melt temperature……..

Refer to material supplier’s Data sheet for recommended settings

And use it as starting point **and starting point only**
Fig. 10-27  Heat content of plastics.
Temperature

What is important….Barrel temperature or Melt temperature?

Optimum **MELT TEMPERATURE** is the key to successful molding

Factors affecting melt temperature

- Barrel temperature settings
- Screw speed
- Screw back pressure
- Residence time
- Cycle time

*Figure 2-11.* Melt temperature affects required injection pressure for 16 classes of materials.
IN ORDER TO REPRODUCE THE SAME PROCESS ON MULTIPLE MACHINES MELT TEMPERATURE IS ONE VARIABLE THAT MUST BE CONTROLLED AND DUPLICATED
How to measure melt temperature?

• Needle Pyrometer

30-30 Melt temperature Rule

Procedure:
• Spray the probe with mold release
• Heat the probe 30º F above the front zone temperature.
• With the machine on cycle, retract the injection unit, Purge.
• Place the heated probe into the melt puddle (Purging mass).
• Wait 30 seconds and record temperature shown on the instrument.
Flow rate

All Plastics exhibit Non-Newtonian behavior........
Newtonian: Shear rate has no effect on viscosity........Water
Non–Newtonian: Viscosity varies with shear rate
Plastics material’s viscosity decreases as shear rate increases

WHY IS THIS IMPORTANT??????
• Screw speed........Lower viscosity at higher screw rpm
• Injection speed.....Flows easier with higher injection speed

Flow rate (Injection speed, velocity) = Time in seconds, measured from start of injection to transfer to pack/hold
How Does velocity profiling help?

- Allows the mold to be filled as fast as possible
- Reduces burning, splay and other aesthetic issues
- Helps with weld line
- Surface finish
- Best speed for each area of the segment can be selected
Pressure

What is pressure?

Pressure is Resistance to FLOW

Injection Pressure    1\textsuperscript{st} stage pressure
Packing/Holding Pressure    2\textsuperscript{nd} stage pressure
Back Pressure

Cavity Pressure    Most Important

Best indicator of what the melt is doing in the mold
Hydraulic pressure Vs. Plastic pressure

Hydraulic pressure: Measure of how much force a machine can generate against the ram

Plastic (Melt) Pressure: Pressure generated in the nozzle of a molding machine usually derived from the intensification ratio of the machine

Cavity Pressure: Actual pressure in the cavity (Mold).
Why is plastic pressure important?

Plastic pressure is what pushes plastic melt into the mold

**NOT**

Hydraulic pressure

Machines are sold with varied intensification ratio and therefore it generates different plastic pressures

Because of these different intensification ratios one cannot use the same hydraulic pressure from machine to machine
Time

Injection

Pack and Hold .......... Gate freeze study

Cooling

Mold Open

Mold Close

**Cooling Time**

BTU’s In = BTU’s OUT

Cooling time = 150 x Thickest wall of the part

= 150 x .100 = 15 sec
Mold Packing and holding

The ideal holding time is the gate freeze time and can only be determined by gate freeze study.

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John Bozzelli
Injection Molding Solutions
www.scienticmolding.com
Flow rate or Water temperature?

Reynolds Number = 3600 x GPM / Diameter x KV

GPM (water flow from hose to mold in gallons per minute)
Diameter of the waterline in inches
KV  kinematic Viscosity of water at 78 F is 1.00

Reynolds number should be greater than 4000 to 5000

For **Turbulent Flow**

• Most plants do not have adequate water flow
### Approximate flow rate needed to produce turbulent flow* in drilled passages

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>ID of drilled passage</th>
<th>Min. flow rate for turbulent flow (gal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16 NPT</td>
<td>0.250</td>
<td>0.33</td>
</tr>
<tr>
<td>1/8 NPT</td>
<td>0.339 R drill</td>
<td>0.44</td>
</tr>
<tr>
<td>1/4 NPT</td>
<td>0.438 7/16- drill</td>
<td>0.55</td>
</tr>
<tr>
<td>3/8 NPT</td>
<td>0.593 19/32- drill</td>
<td>0.74</td>
</tr>
<tr>
<td>1/2 NPT</td>
<td>0.719 23/32- drill</td>
<td>0.90</td>
</tr>
</tbody>
</table>

For good Reynolds Number (turbulent flow)........
Minimum GPM = 3.5 x pipe I.D.

***Alternate Rule of Thumb:***

7/16' Diameter Waterline requires
1.5 GPM to achieve turbulent flow.

Source: Practical Mold Cooling by Philip Burger, Burger Engineering
Cooling Considerations

- Molding Cycle.......80% is cooling time
- Flow type....Laminar or Turbulent
- Flow rate......GPM
- Reynolds number of > than 5000 for turbulent flow
- Thermal conductivity of mold steel
- Plastic material’s Heat Content
- Waterlines
- Part Design
Table 3. Heat removal at different melt temps for HDPE

<table>
<thead>
<tr>
<th>Melt Temp</th>
<th>Heat removed</th>
<th>Throughput rate</th>
<th>Cycle time</th>
</tr>
</thead>
<tbody>
<tr>
<td>500°F</td>
<td>36,400 Btu/hr</td>
<td>100.00 lb/hr</td>
<td>11.23 s</td>
</tr>
<tr>
<td>400°F</td>
<td>30,000 Btu/hr</td>
<td>100.00 lb/hr</td>
<td>11.23 s</td>
</tr>
<tr>
<td>400°F</td>
<td>36,400 Btu/hr</td>
<td>121.36 lb/hr</td>
<td>9.27 s</td>
</tr>
</tbody>
</table>

Overall productivity improvement: 21.3%

1 Calculations based on cooling from stated melt temp. to 100°F part removal temp.
2 Calculations do not include ambient heat gain load.

Source: Injection Molding Magazine article

Figure 2: De-mold temperature

Source: Omnexus Article
Flow Rate Monitoring

www.smartflow-usa.com
Proper water management

Is the supply pressure adequate (50 psi min)?
Is the return pressure at least 40 psi less than the supply? (10 psi)

NO-NO (oh! No!)
Special techniques

- Heat pipes (Thermal Pin)
- High thermal conductivity alloys
- “Melt Flipper” to balance parts

Pulse cooling
Universal Set Up

As long as you push the same amount of material at the same rate, at the same position…..

You should be able to move a mold and material from machine to machine with set up data that is universal to all machines anywhere in the world.
Universal set up card

Actual Melt temperature

Fill Data: Time__________ PPSI__________ Weight______

Pack & Hold Data: Time__________ PPSI__________ Weight______

Cooling data:

Temperatures______________________________

Pressures (PSI)______________________________

Flow rate (GPM)
The Universal Setup Card

Mold number, number of shots to date, part name, customer, date, molder's name, and any other information your plant may require.
Fill time for a part 95 to 99 percent full.
Weight and picture of part 95 to 99 percent full.
Transfer volume, transfer position, or cavity pressure (time and hydraulic pressure transfer modes are not recommended).
Nozzle melt pressure range for different lots at transfer volume, position, or cavity pressure.
First stage set melt pressure (nozzle); this is first stage set pressure times the intensification ratio.
Cycle time.
Quoted cycle time(s).
Gate seal time.
Pack and hold time.
Pack and hold melt pressure.
Shot size in volume.
Mold temperature, cooling channel map.
Water flow diagram, with gallons/minute of each channel, temperature of water in and out, and water pressure in and out.
Screw run time (average).
Mold open and closed time, cure time, or cooling times.
Melt temperature via hot probe.
Nozzle tip length, diameter, land length, radius, and type.
Hydraulic pressure vs. time response curve.
Cavity pressure integral at the gate and end of fill.
Molding Operation Essentials

• Accurate gram scale (Gate seal study and check ring repeatability study)
• Digital pyrometer
• Stop watch
• Flow meter
• Dew point meter
• Dial indicator with magnetic base to check mold deflections
Automation in Injection Molding

Tooling............Subgates, Hot Runners
Part separators
Regrind feedback
Robotics
“Lights Out” Molding
<table>
<thead>
<tr>
<th>Integration Level</th>
<th>Function</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Automation: One post-mold operation is performed by the parts-removal robot or one downstream device.</td>
<td>Degating</td>
<td>Drop sprue in granulator.</td>
</tr>
<tr>
<td>Flex/ Close</td>
<td>Flex living hinge. Snap shut one-piece closures.</td>
<td></td>
</tr>
<tr>
<td>Multiple Positioning</td>
<td>Separate parts from family molds. Isolate parts from bad cavities. Isolate parts if production parameters are not met. Place parts in separate bins or on conveyors. Place parts in fixtures or trays. Stack parts.</td>
<td></td>
</tr>
<tr>
<td><strong>Machining</strong></td>
<td>Drill, mill, degate, trim gate vestige.</td>
<td></td>
</tr>
<tr>
<td>Quality Control</td>
<td>Check dimensions with vision system or contact gaging. Check for presence of features using vision systems, contact gages, or sensors. Weigh and count parts. Perform leak/pressure testing.</td>
<td></td>
</tr>
<tr>
<td><strong>Bagging</strong></td>
<td>Bag single parts for protection. Bag multiple parts for shipping. Bag family mold parts.</td>
<td></td>
</tr>
<tr>
<td>Complex Automation: Parts-removal robot works with secondary equipment</td>
<td><strong>Packaging</strong></td>
<td>Load and stack trays. Box parts with single or multiple layers per box.</td>
</tr>
<tr>
<td>Serialization and Decorating</td>
<td>Deliver parts to laser or impact printer, self adhesive labeler, hot stamper, or pad printer.</td>
<td></td>
</tr>
<tr>
<td>Assembly (one to three operations is typical)</td>
<td>Deliver parts for ultrasonic welding or adhesive bonding. Screw parts together. Snap fit parts. Place metal fasteners</td>
<td></td>
</tr>
</tbody>
</table>
Why All Electric?

Global market for all-electric injection moulding machines

Sales of all-electric machines in 2006

17,900 all-electric machines were sold 2006
All Electric Molding Machines

• Technology developed in early 1980 in Japan
• Introduced in USA by Milacron in 1985 at NPE
• Initially available in 50 to 150 tons sizes only
• Today up to 2000 ton all-electric machines available
• Term All-Electric implies use of servomotors on both clamp and injection end
• 5 to 20% higher in cost
• Over 30 machine manufacturers offer all-electric machines

• #1 advantage.....Energy Savings
All Electric Molding Machines

- Energy savings form 25% to 60%
- Repeatability, Accuracy, Consistency
- No hydraulic oil…clean
- No cooling water cost
- Quiet
- Low maintenance

- Slightly Higher cost
- Torque related issues….Long Hold times…PVC
- Injection Carriage pressure
- Unscrewing molds?
- Core Pulls?
EDUCATION is the key to successful Implementation of Scientific Molding
Plastics Engineering Technology Certificate

This four-course certificate program provides practical instruction applicable to materials, processing, product design and tooling. The program is targeted to technical and non-technical audiences desiring to acquire basic knowledge, expand their horizon, enhance their career or simply take as a refresher course. The main emphasis is on practical aspects of Plastics Engineering Technology without being extremely technical so that the knowledge achieved can be applied in day-to-day applications.

PLASTICS: THEORY AND PRACTICE  WINTER

SCIENTIFIC INJECTION MOLDING  SPRING

PLASTICS PART DESIGN FOR INJECTION MOLDING  SUMMER

TOOLING FOR INJECTION MOLDING  FALL

WWW.CEU.CSUPOMONA.EDU
Where to get more information…

Links to articles

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http://www.immnet.com/articles?article=1705
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