Scientific Approach to Injection Molding

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Consultek
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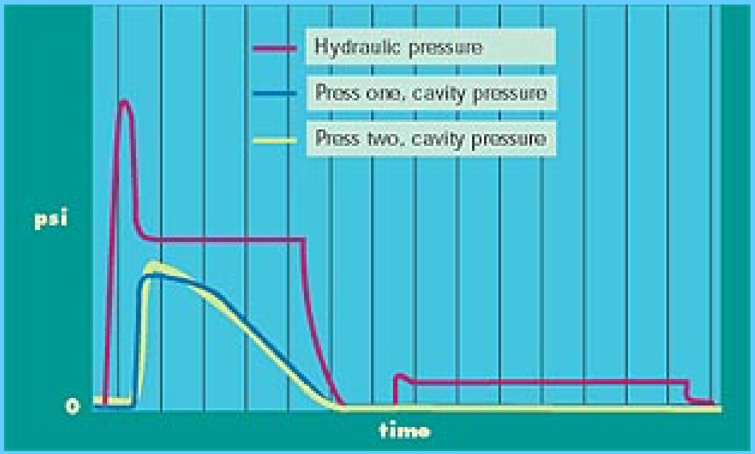


What is Scientific Approach to Injection Molding?

- 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

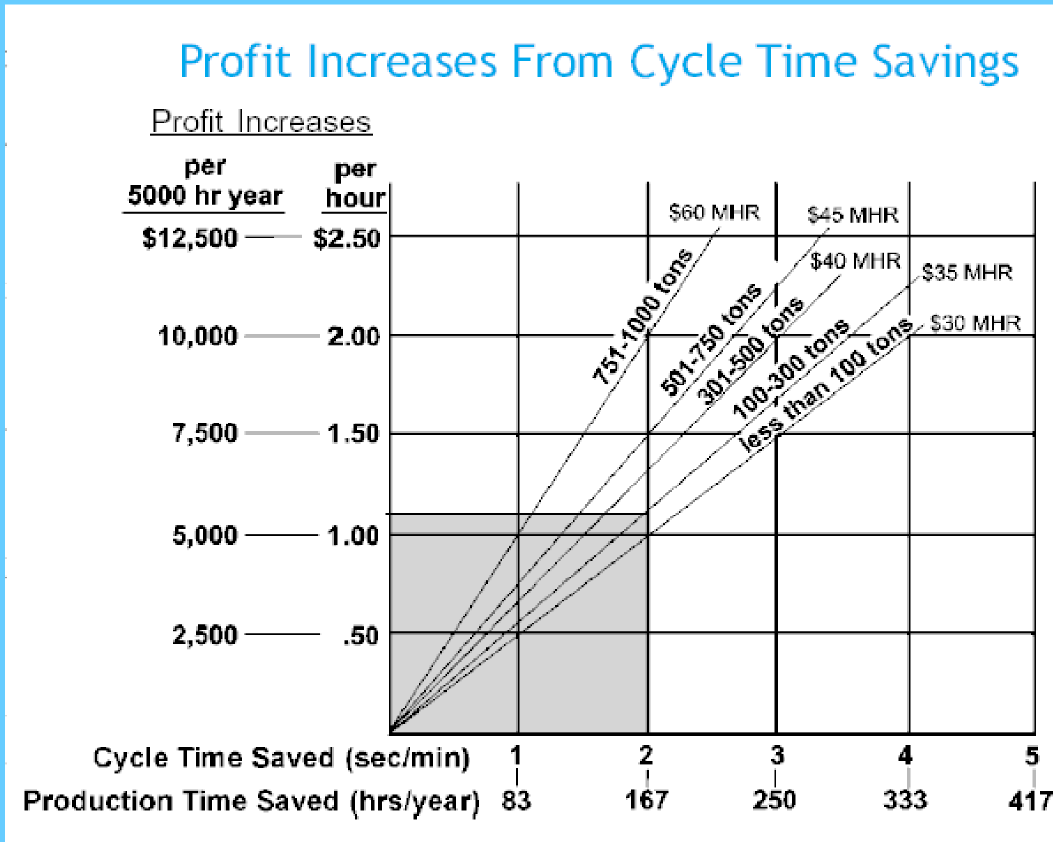
Old Ways	To	**New Ways**
How		**How & Why**
Art (sight, sound and touch)		**Science**
Myth		**Facts**
Jet container approach		**TDK approach**

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?
GaGGGahh...
...Gagggggghhh...

What's One Second Worth?

How about $58,500 per year?



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."

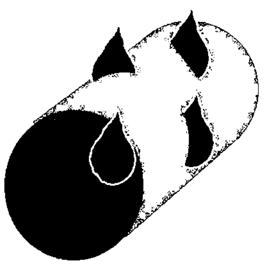
Materials Drying

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.

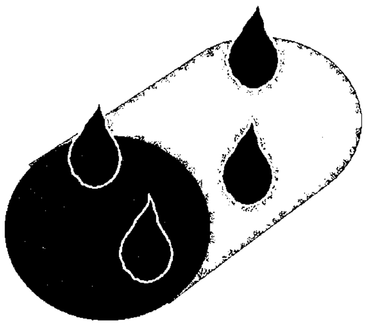
Hygroscopic	Non Hygroscopic
Polymers with high affinity for moisture	Polymers with very little or no affinity for moisture
Moisture is absorbed into the pellet over time until equilibrium is reached	No absorption of moisture into the pellet. May pick up surface moisture.
Nylon, ABS	Polystyrene
Polycarbonate	Polyethylene
Polyester	PVC, Polypropylene
Polyurethane	Acetal
Desiccant Dryer	Hot Air Dryer

Hygroscopic Pellet



Moisture is absorbed into the Pellet

Non-Hygroscopic Pellet



Surface Moisture

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

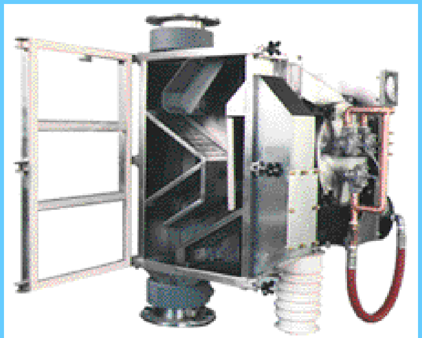
- Measures actual moisture in the material
- Very accurate measurement
- Lab environment/very clean production area
- Preprogrammed material data
- $ 8000 and up

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

$$\frac{L}{D} = \frac{\text{Flight length of screw}}{\text{Outside diameter of screw}}$$

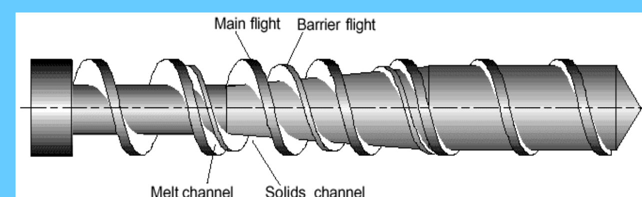
$$\text{Compression Ratio} = \frac{\text{Depth of feed section}}{\text{Depth of metering section}} = \frac{D_f}{D_m}$$

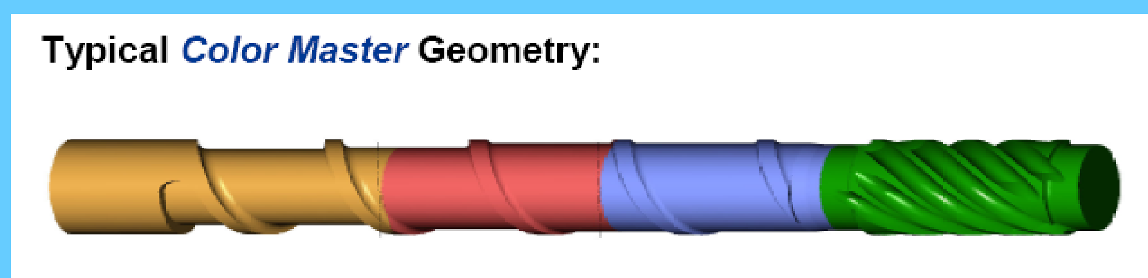
Figure 4C

Compression Ratio

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

Barrier & Mixing Screws





Non Return Valve

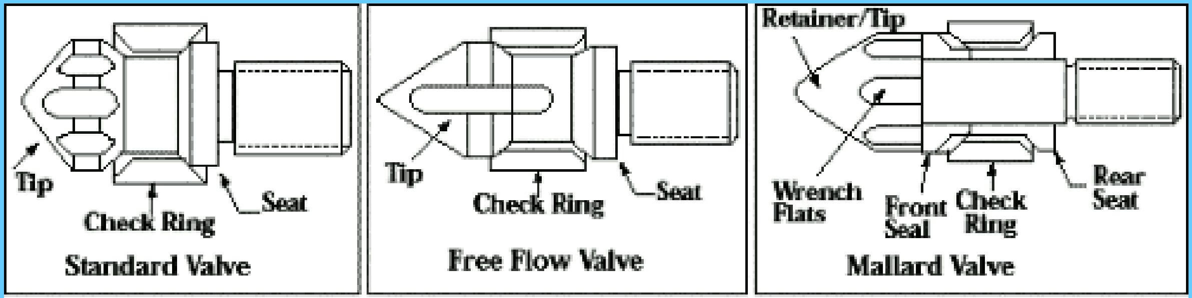


Figure 4J Figure 4K Figure 4L

<u>Check Ring Repeatability Study</u>

A. Set up machine to run standard parts

B. Turn off pack and hold time and pressure

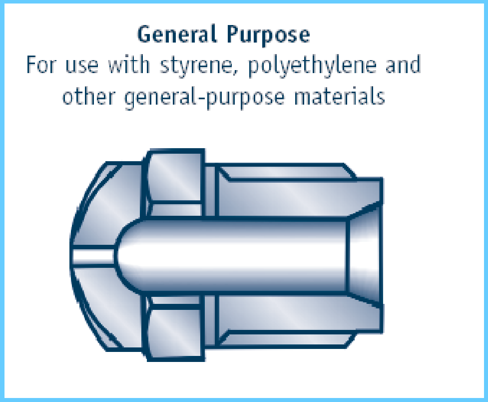
C. Make 10 Fill only shots

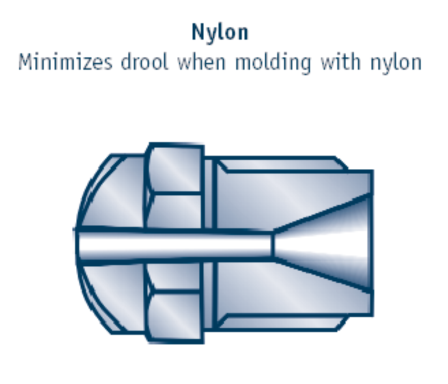
D. Weigh the parts and record weight

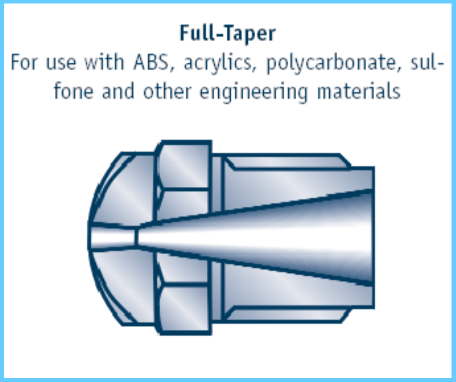
E. Calculate

Acceptable variation is 5% max.

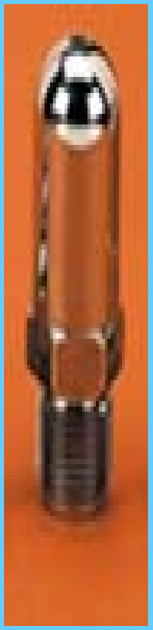
Nozzle Tip Types







Avoid Long Reach Nozzles & tips



- **Cold slug**
- **Burning**
- **Splay**
- **Pressure loss**

Mold Venting

<u>Why Vent?</u>

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

<u>Problems associated with poor venting</u>

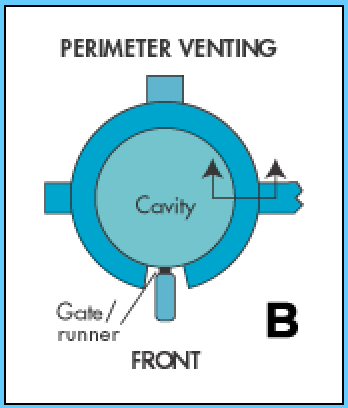
- Burn marks
- Poor mold filling
- Weak weld lines
- Internal bubbles and non-fill areas
- High stress concentration
- Sink marks
- Longer cycle time
- Mold deposit build-up
- Down time
- Decorating problems
- Adhesion problems
- Stress cracking in presence of chemical

VENT THE RUNNER….

PERIMETER VENTING

<u>YOU CAN'T HAVE TOO MUCH VENTING!!!!!</u>

VENTING



Porcerex II Vent Pins

If porous metal pins gets too hot & plugged

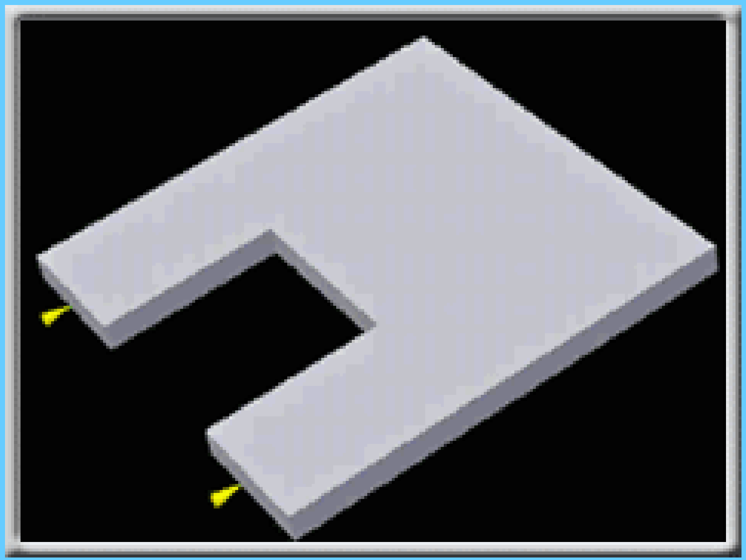
Use

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

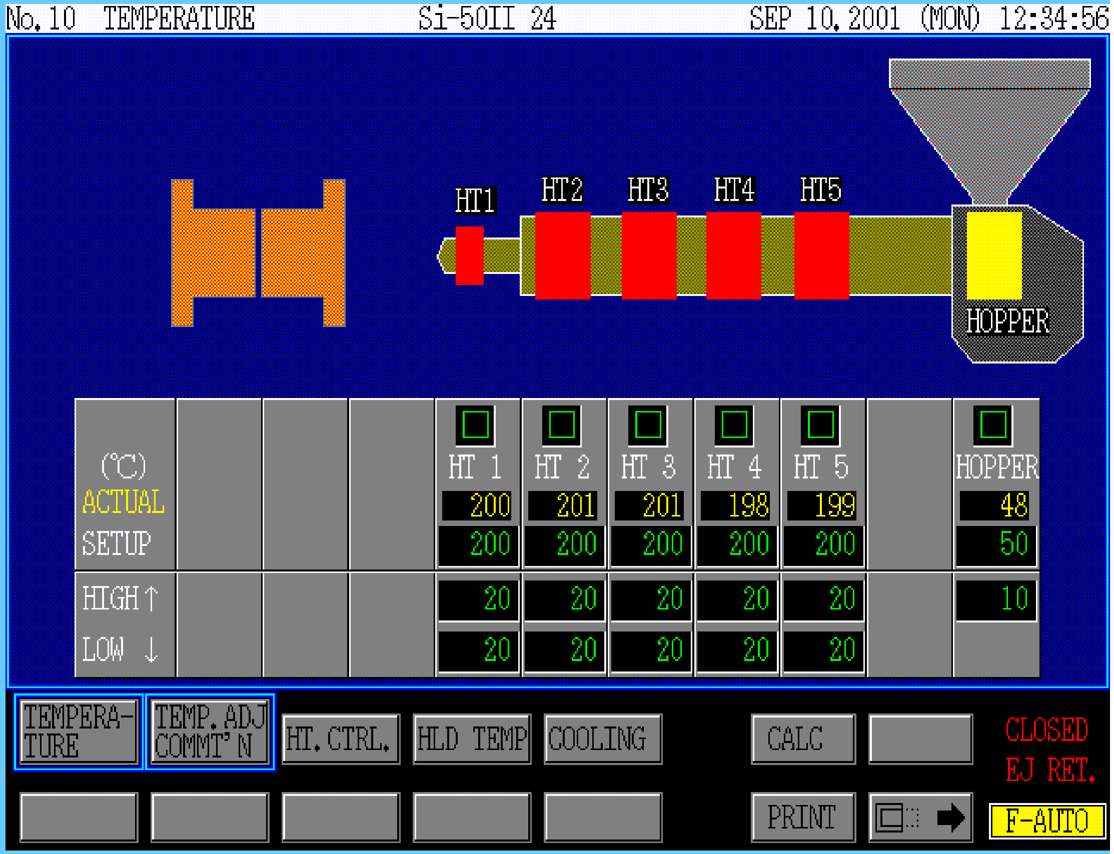
Where does the heat to melt the polymer come from?

External Heater bands

Internal 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

<u>Melt temperature affects cycle time</u>

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 **<u>and starting point only</u>**

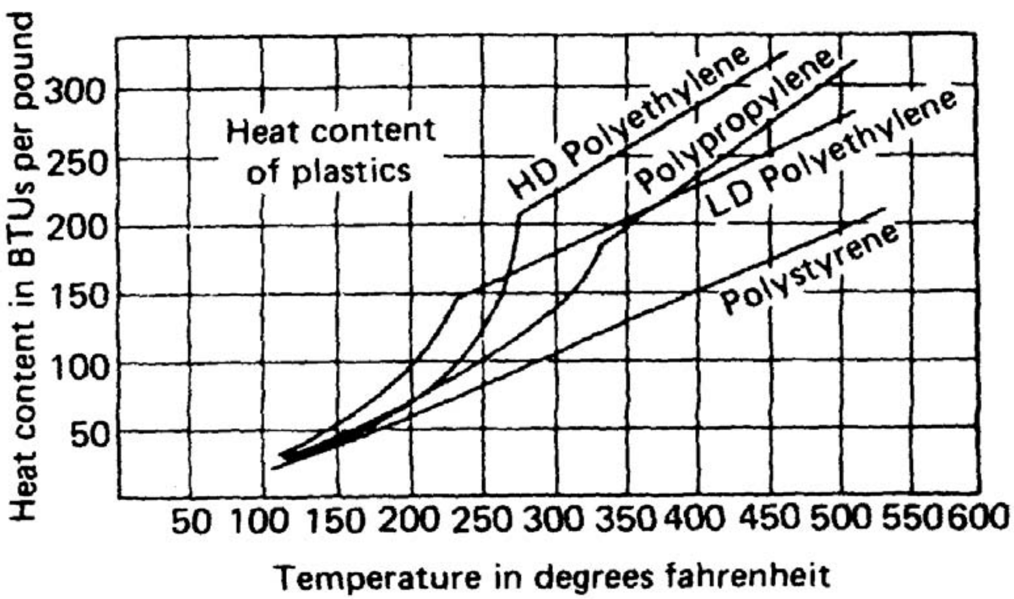


Fig. 10-27 Heat content of plastics.

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

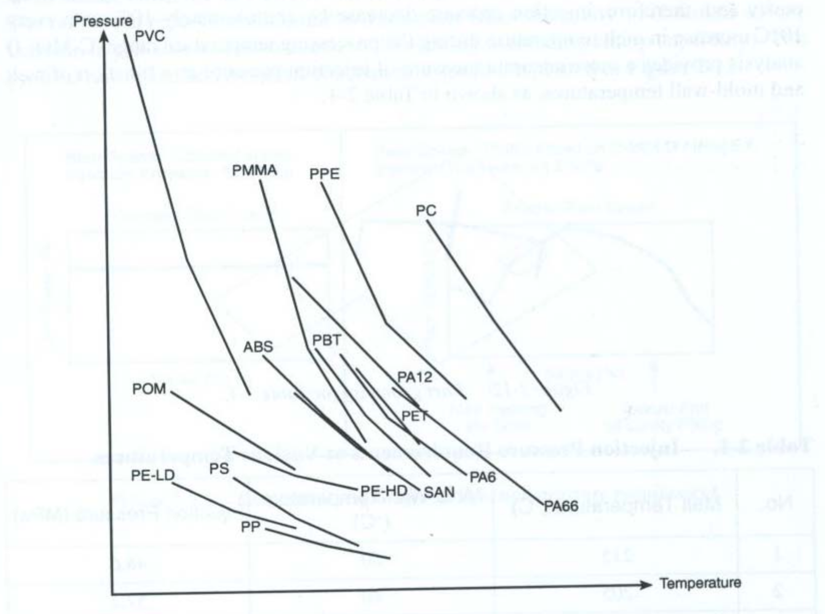


Figure 2-11. Melt temperature affects required injection pressure for 16 classes of materials.

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 **1st stage pressure**

Packing/Holding Pressure **2nd 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

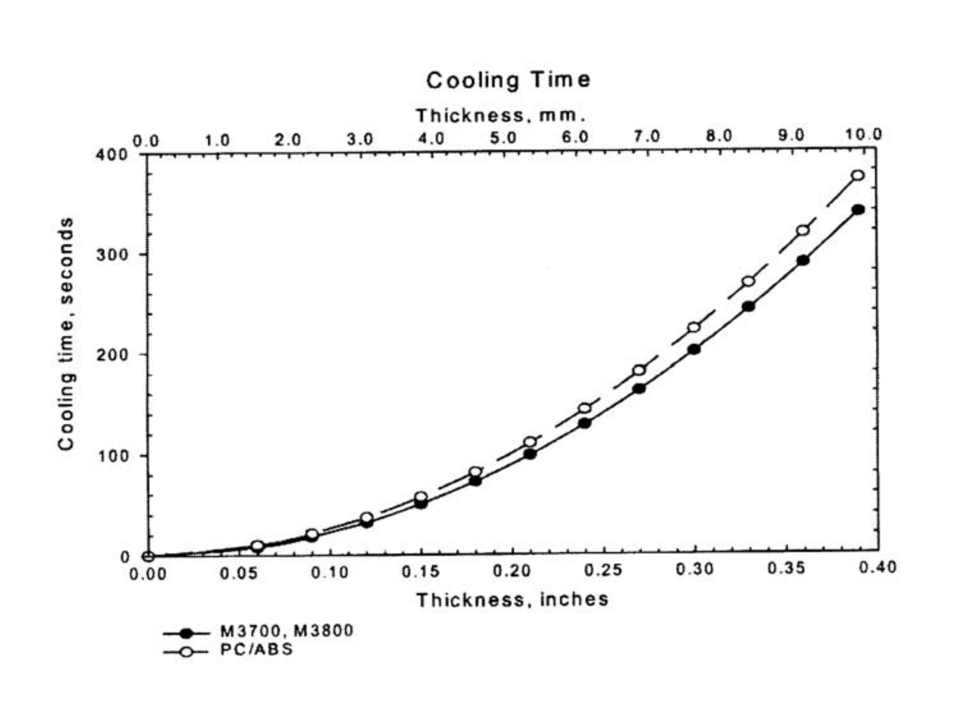
Injection

Pack and Hold………..Gate freeze study

Cooling

Mold Open

Mold Close



<u>Cooling Time</u>

BTU's In = BTU's OUT

Cooling time = 150 x Thickest wall of the part

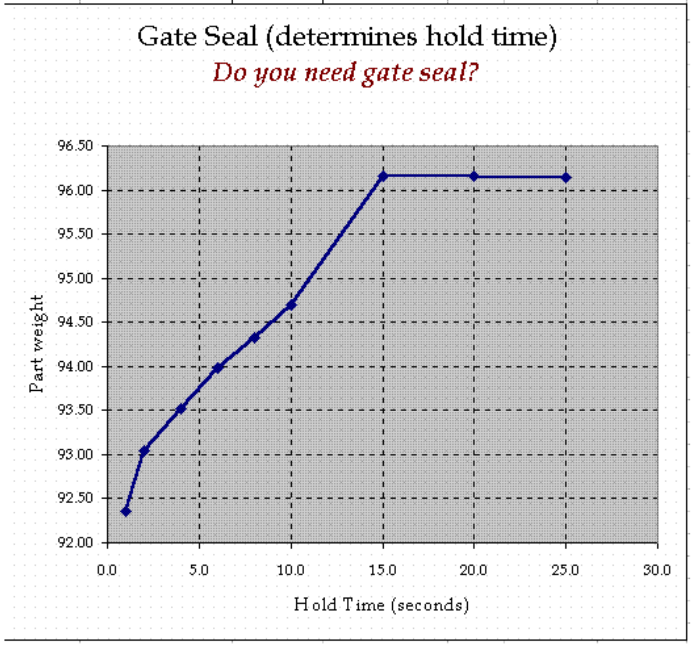
= 150 x .100 = 15 sec

Mold Packing and holding

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

Gate Seal

Shot #	Hold Time seconds	Part Weight Grams	Cycle Time seconds	Date: 1/26/00
1	25.0	96.14	42.8	
2	20.0	96.16	37.8	
3	15.0	96.15	32.8	
4	10.0	94.69	27.3	
5	8.0	94.32	27.7	
6	6.0	93.98	27.7	
7	4.0	93.52	27.7	
8	2.0	93.05	27.3	
9	1.0	92.36	27.3	*All cycle times*
10				*should be identical*



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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)

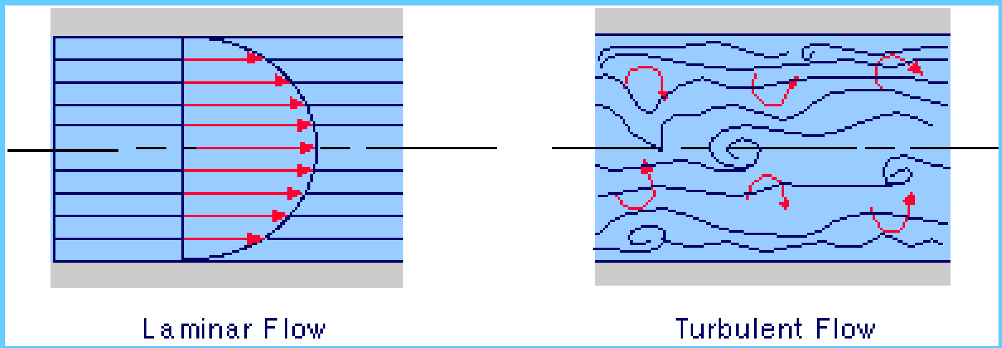
Diameter of the waterline in inches

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*

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

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

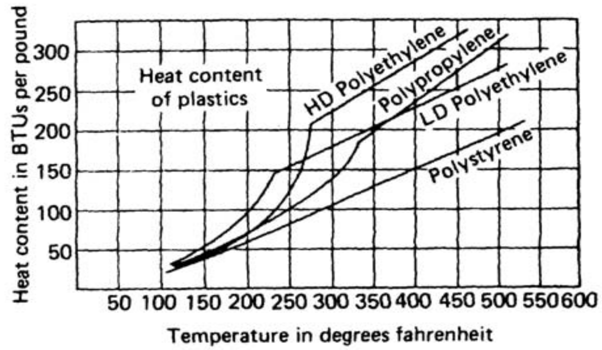
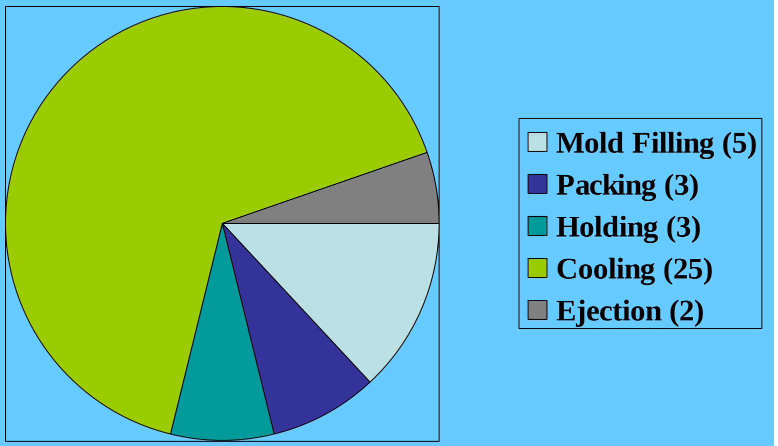


Fig. 10-27 Heat content of plastics.



Optimizing Cycle Time

Table 3. Heat removal at different melt temps for HDPE

	Heat removed	Throughput rate	Cycle time
[1,2] 500°F melt temp	36,400 Btu/hr	100.00 lb/hr	11.23 seconds
[1,2] 400°F melt temp	30,000 Btu/hr	100.00 lb/hr	11.23 seconds
[1,2] 400°F melt temp	36,400 Btu/hr	121.36 lb/hr	9.27 seconds
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

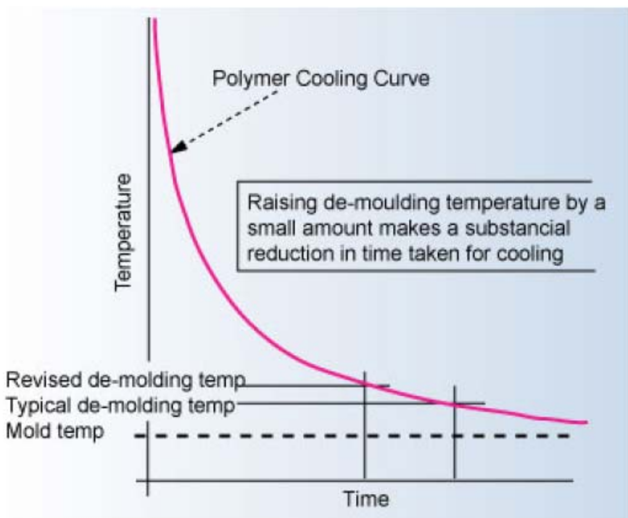
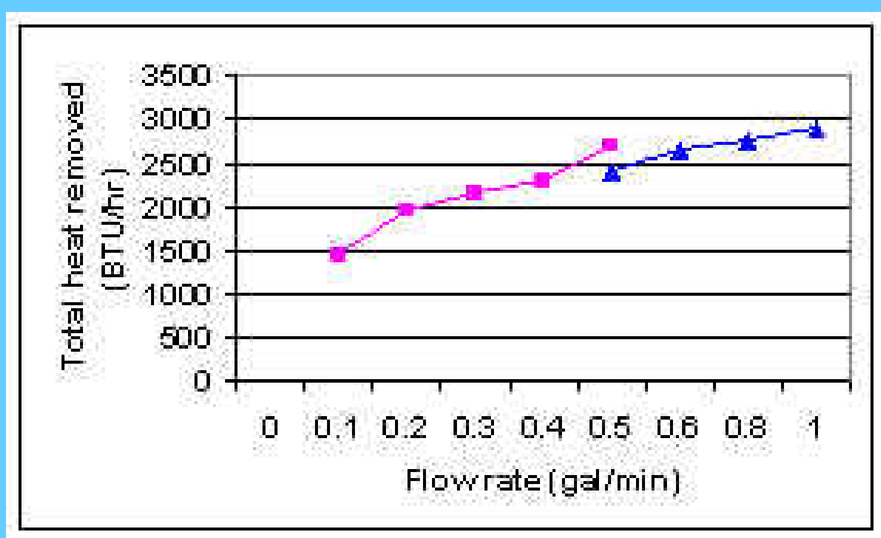


Figure 2: De-mold temperature

Source: Omnexus Article

Flow Rate Monitoring



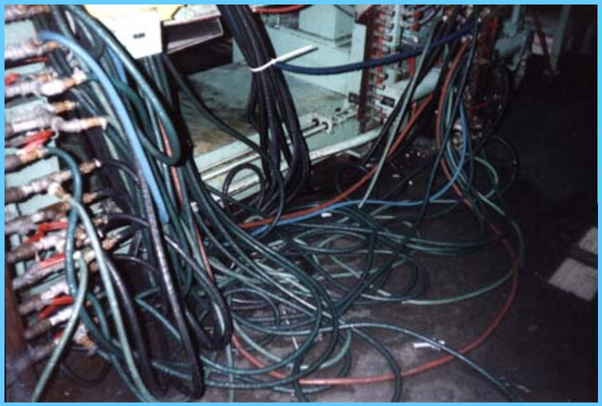
www.smartflow-usa.com

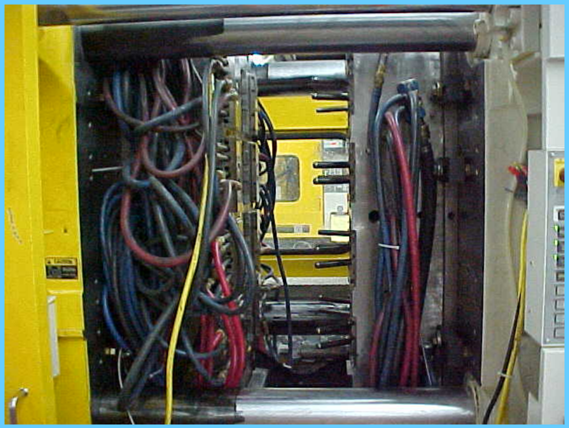
Proper water management

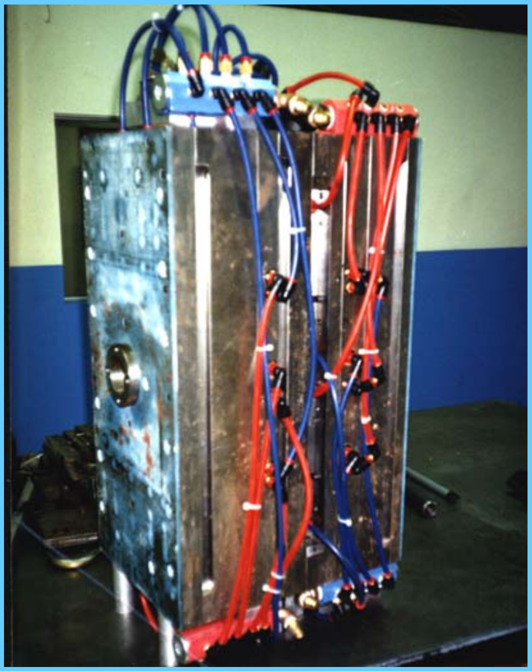
Is the supply pressure adequate (50 psi min)?

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

NO-NO (oh! No!)

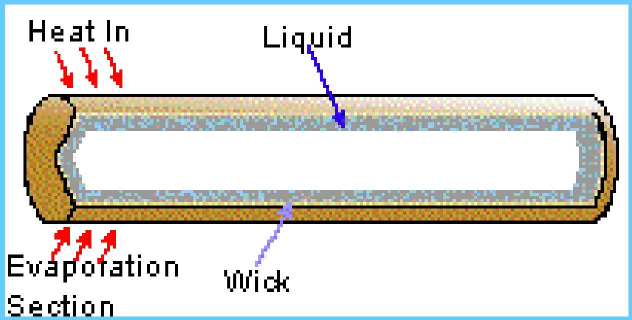






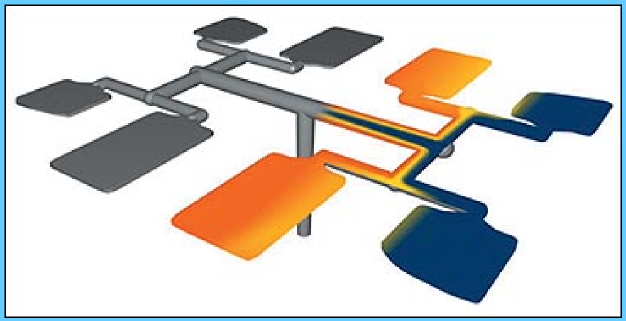
Special techniques

- **Heat pipes (Thermal Pin)**

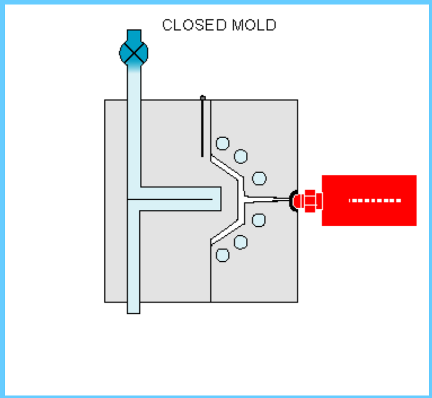


- **High thermal conductivity alloys**

- **“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 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

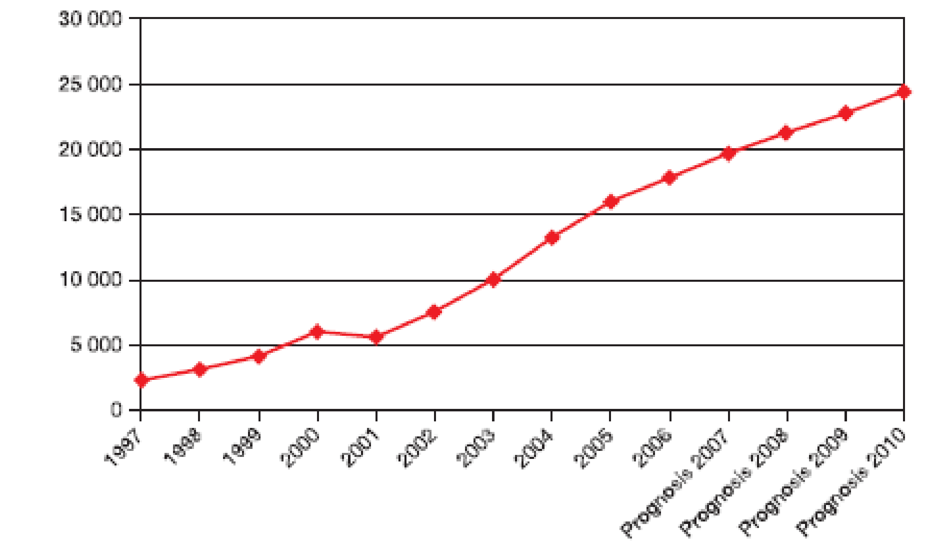
AUTOMATION

Source: Plastics Technology

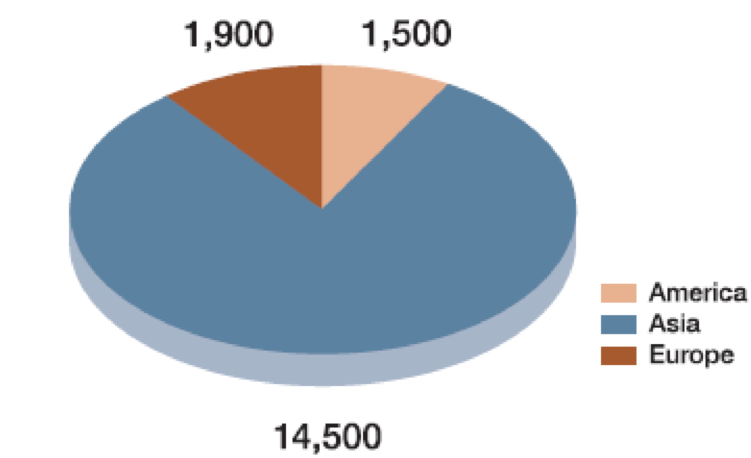
Integration Level	Function	Examples
Simple Automation: One post-mold operation is performed by the parts-removal robot or one downstream device.	Degating	Drop sprue in granulator.
	Flex/ Close	Flex living hinge. Snap shut one-piece closures.
	Multiple Positioning	Separate parts from family molds. Isolate 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.
	Machining	Drill, mill, degate, trim gate vestige.
	Quality Control	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.
	Bagging	Bag single parts for protection. Bag multiple parts for shipping. Bag family mold parts.
Complex Automation: Parts-removal robot works with secondary equipment	Packaging	Load and stack trays. Box parts with single or multiple layers per box.
	Insert Molding	Feed inserts. Grip inserts. Place inserts in tool. Confirm insert placement. Extract finished parts.
	Serialization and Decorating	Deliver parts to laser or impact printer, self adhesive labeler, hot stamper, or pad printer.
	Assembly (one to three operations is typical)	Deliver parts for ultrasonic welding or adhesive bonding. Screw parts together. Snap fit parts. Place metal fasteners

Why All Electric?

Global market for all-electric injection moulding machines



Sales of all-electric machines in 2006



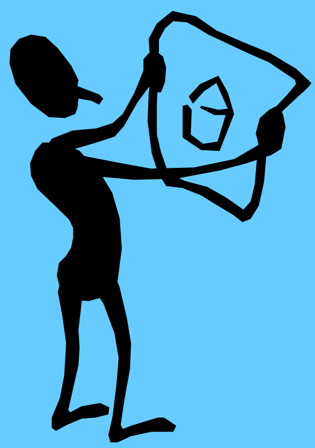
17,900 all-electric machines were sold 2006

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

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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.

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Links to articles

http://www.immnet.com/articles/2003/October/2258
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http://www.smartflow-usa.com/cooling.htm
http://www.tecairinc.com/psmolding.html

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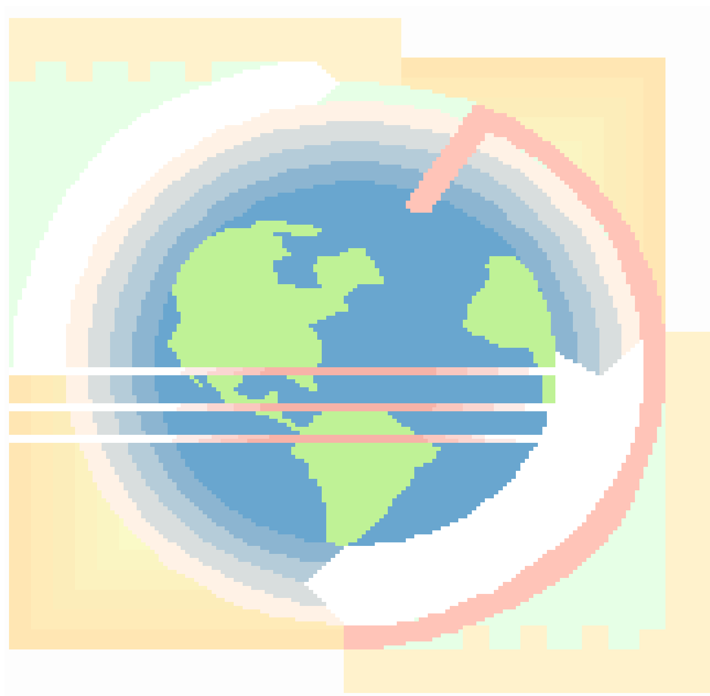

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