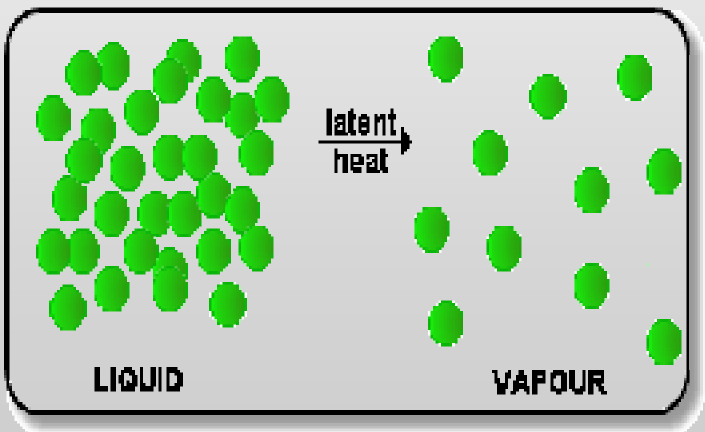
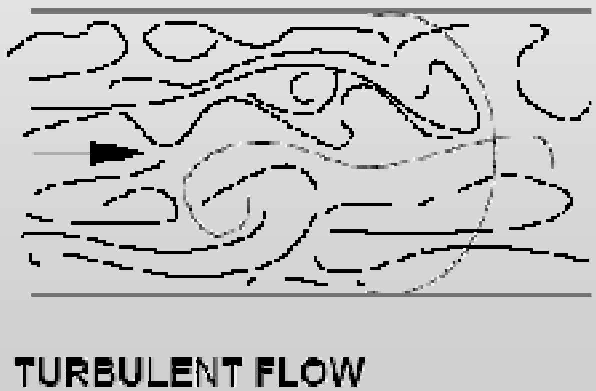
Evaporative Cooling Vs. Conventional (Turbulent Cooling)

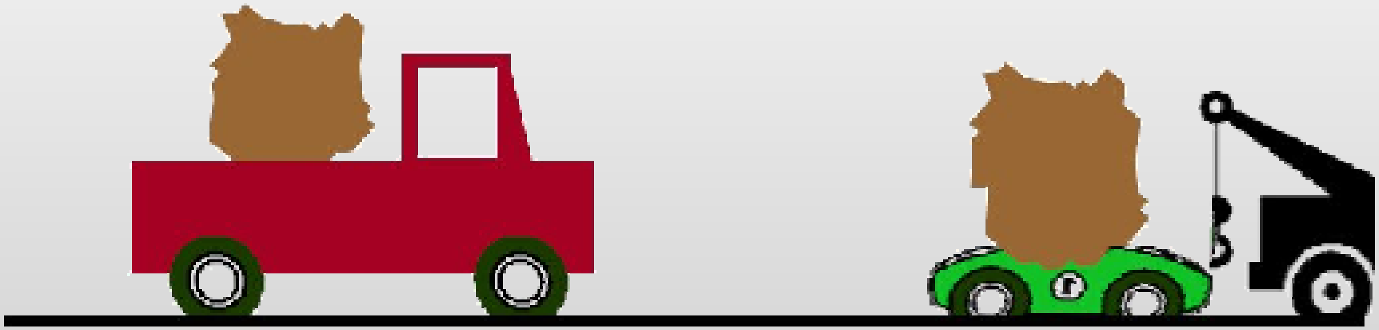


Vs.



Heat Capacity, *C*

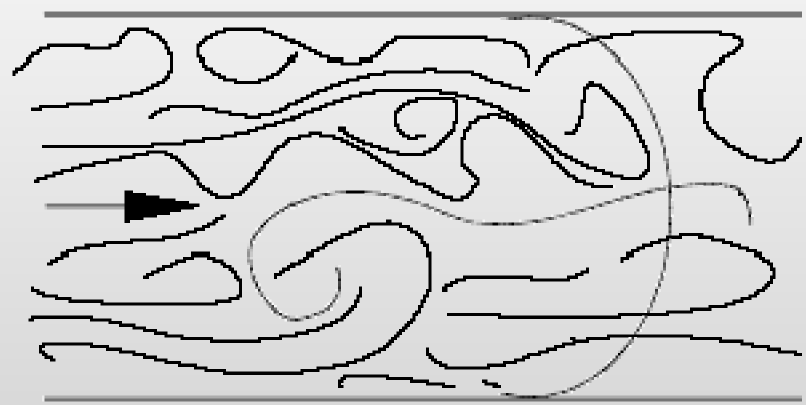
- High heat capacity is the ability of an object to absorb energy with little temperature rise:
  - More heat capacity => Less temperature rise (for given energy input)



The change in temperature is proportional to energy transfered

Specific heat of liquid water, in calories, is 1.00 cal/g x º C.

LAMINAR FLOW



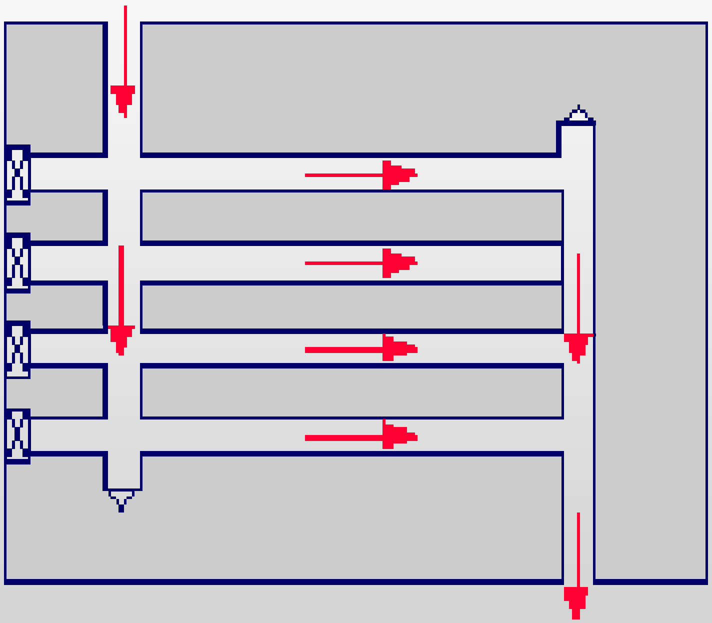
TURBULENT FLOW

Diameter VS Turbulent Flow

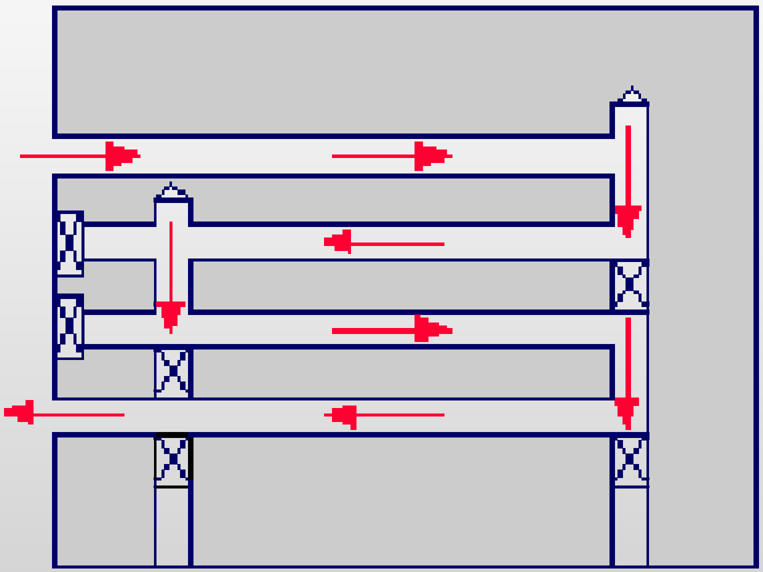
Temperature		40F	60F	80F	100F	120F	140F	160F	180F	200F
Viscosity Centistokes		1.54	1.12	0.86	0.69	0.56	0.47	0.4	0.35	0.31
Inch Diameter		GPM Flow required for Reynolds Number equal to 5000 using water with no additives								
0.188	3/16	0.46	0.33	0.26	0.21	0.17	0.14	0.12	0.10	0.09
0.250	1/4	0.61	0.44	0.34	0.27	0.22	0.19	0.16	0.14	0.12
0.313	5/16	0.76	0.55	0.43	0.34	0.28	0.23	0.20	0.17	0.15
0.375	3/8	0.91	0.66	0.51	0.41	0.33	0.28	0.24	0.21	0.18
0.438	7/16	1.07	0.78	0.60	0.48	0.39	0.33	0.28	0.24	0.21
0.500	1/2	1.22	0.89	0.68	0.55	0.44	0.37	0.32	0.28	0.25
0.563	9/16	1.37	1.00	0.77	0.61	0.50	0.42	0.36	0.31	0.28
0.625	5/8	1.52	1.11	0.85	0.68	0.55	0.46	0.40	0.35	0.31
0.750	3/4	1.83	1.33	1.02	0.82	0.66	0.56	0.47	0.42	0.37
0.875	7/8	2.13	1.55	1.19	0.96	0.78	0.65	0.55	0.46	0.43
1.000	1	2.44	1.77	1.36	1.09	0.89	0.74	0.63	0.55	0.49

FORMULAS: Q=D n Nr / 3160   Nr=3160 Q / D n   Nr=7740 V D / n

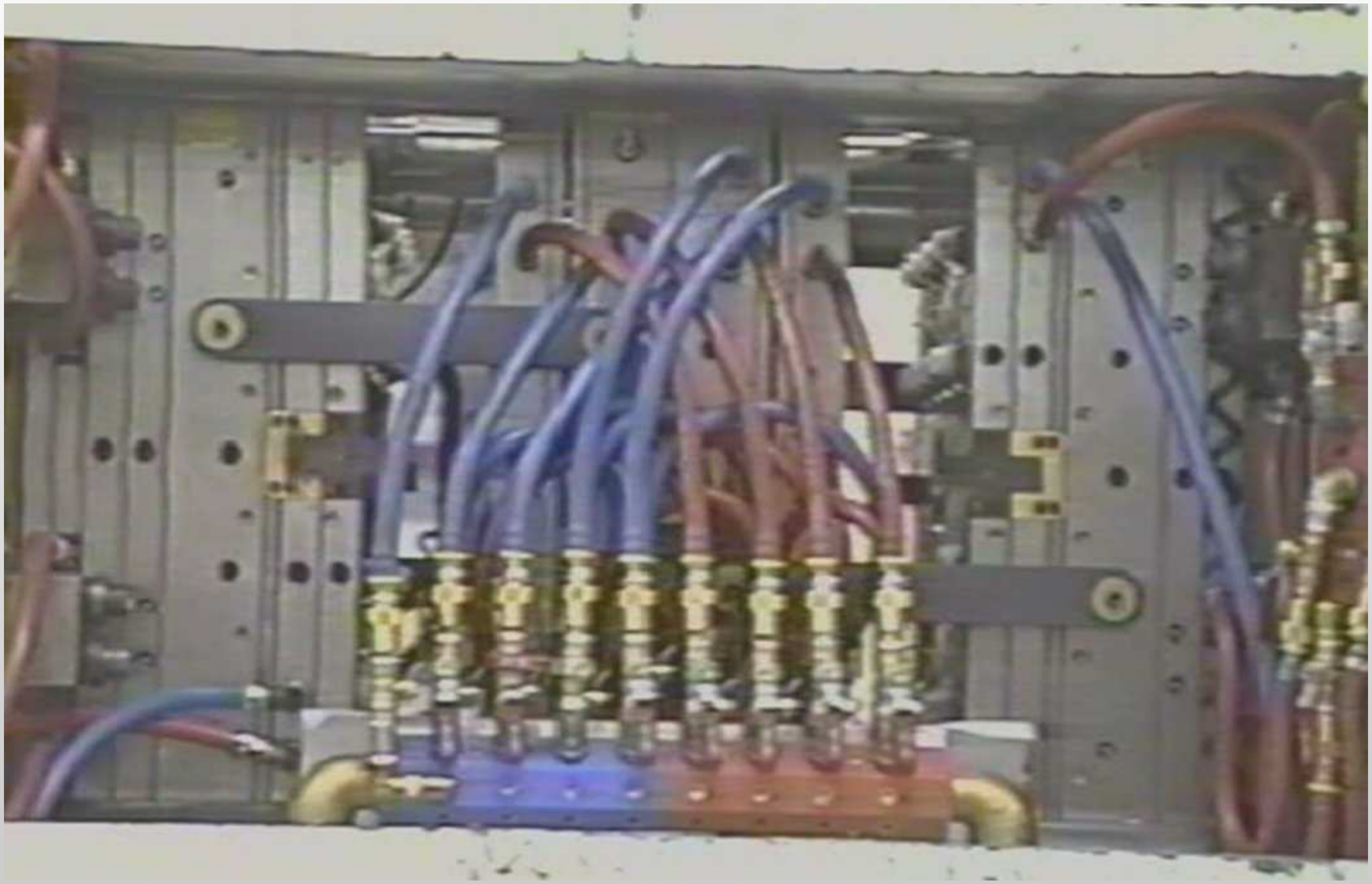
D= Diameter of passage in inches
n= Kinematics viscosity
Nr= Reynolds number (using 5000)
V= fluid velocity in ft/sec



Parallel Cooling Channels



Serial Cooling Channels



"Fundamentals" of Mold Cooling

First, some fundamental basics as Mold Cooling alternatives…….

Removal of heat can be achieved in a variety of ways, each of the following methods having inherent challenges:

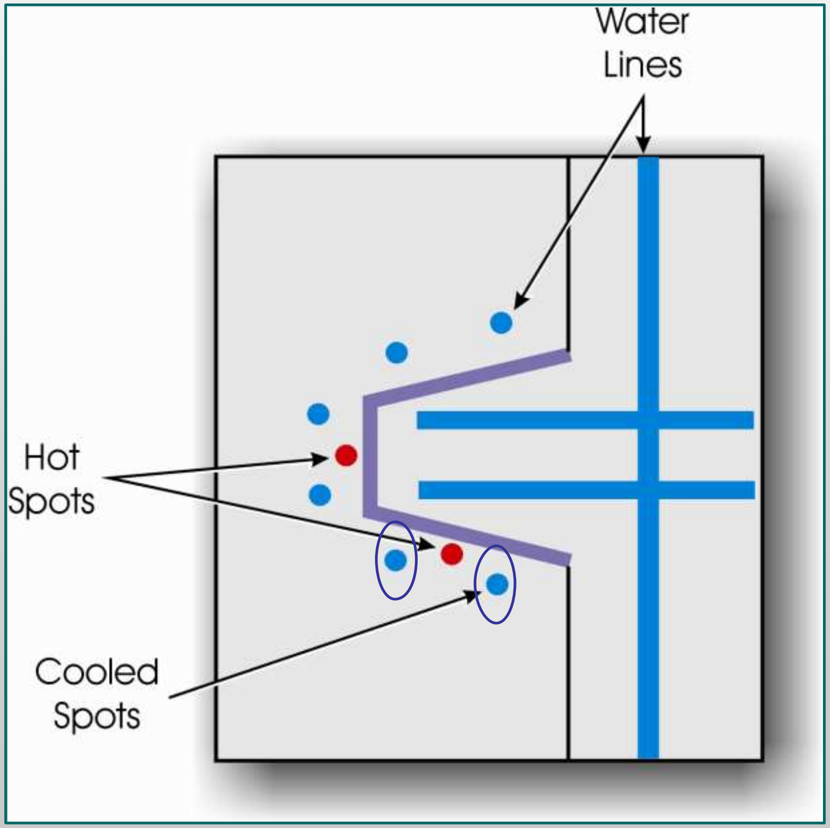
A) Conventional Cooling : basically turbulent water flow

B) Conformal Cooling : water channels "following" molding surface

C) Pulse Cooling

C) Shelling : "soaking" the steel surface

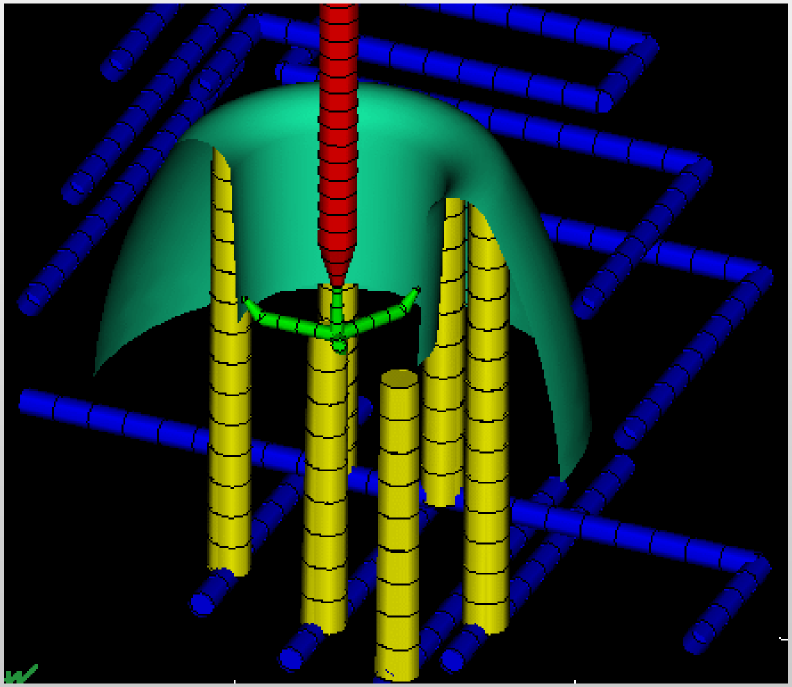
Conventional Cooling Example



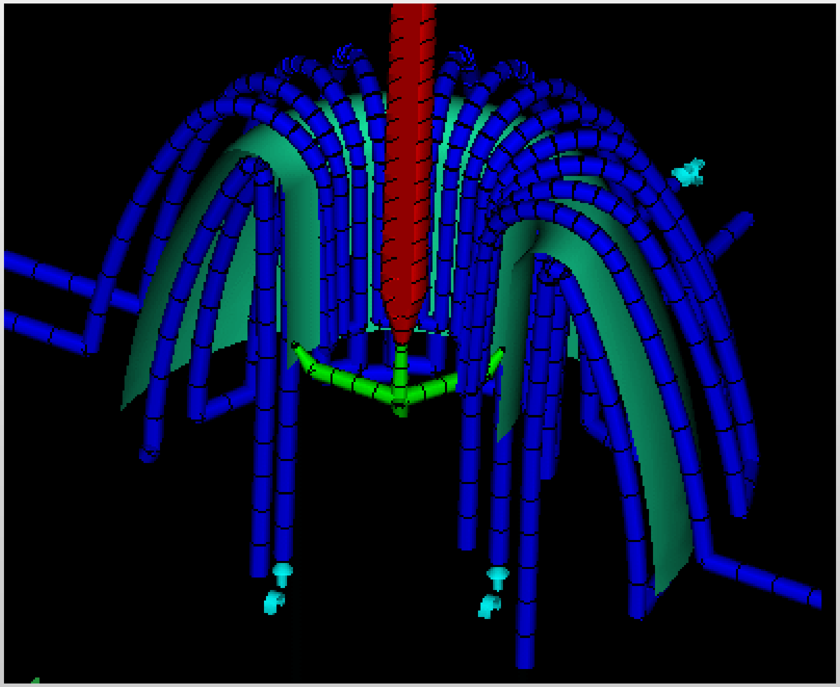
Problems with Conventional Cooling

1. Need for turbulent flow requires high velocity, which conflicts with surface area with which to extract heat.
2. High velocity requires high energy usage/inefficiency.
3. Multiple cooling circuits are most often required.
4. Tooling design features compromised to allow cooling.
5. Flow is always at a maximum, even when not “working”
6. Differential cooling rates cause distortion/quality issues.
7. In many cases, the mold is a cooling jig, extending cycle.
8. Cycle time “driver” is the “hot spot” in the mold.
9. Cooling with drilled holes is inherently uneven.
10. Corrosion and scale build up, stress fractures, failures, maintenance.

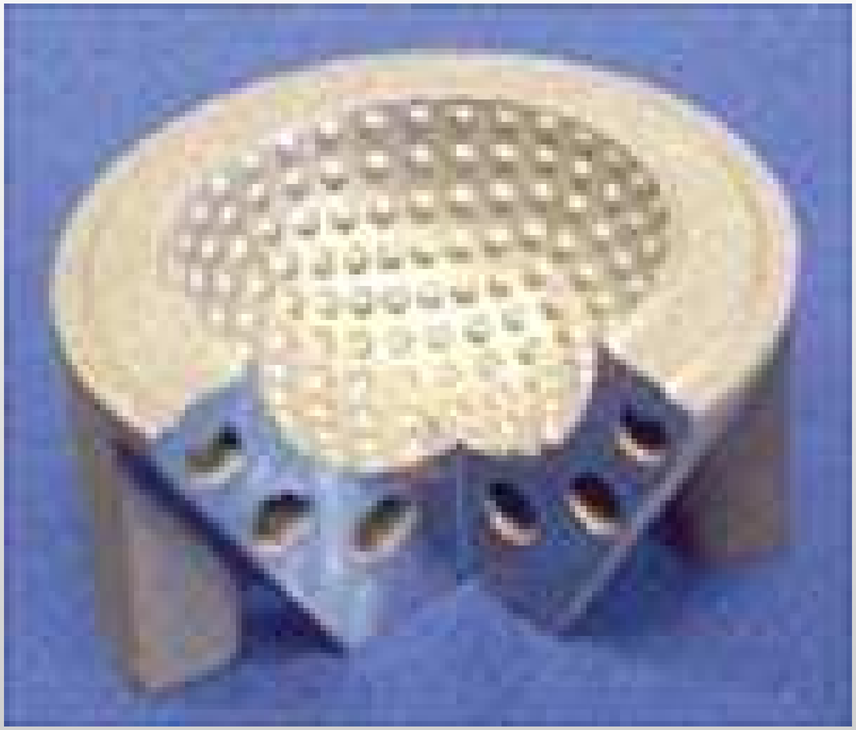
Conventional gun drilled cooling circuit



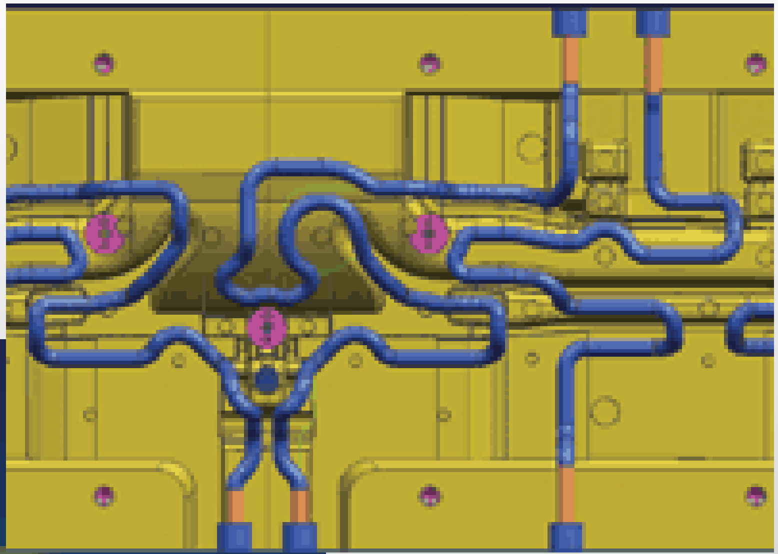
Conformal cooling circuit

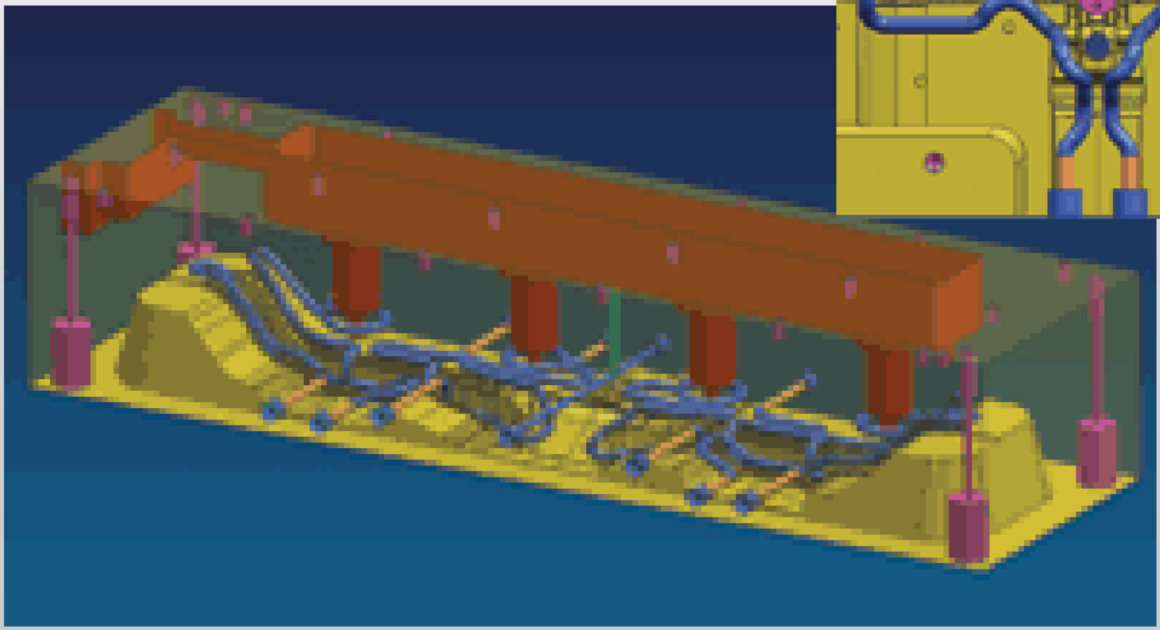


Conformal cooling circuit



Conformal cooling circuit

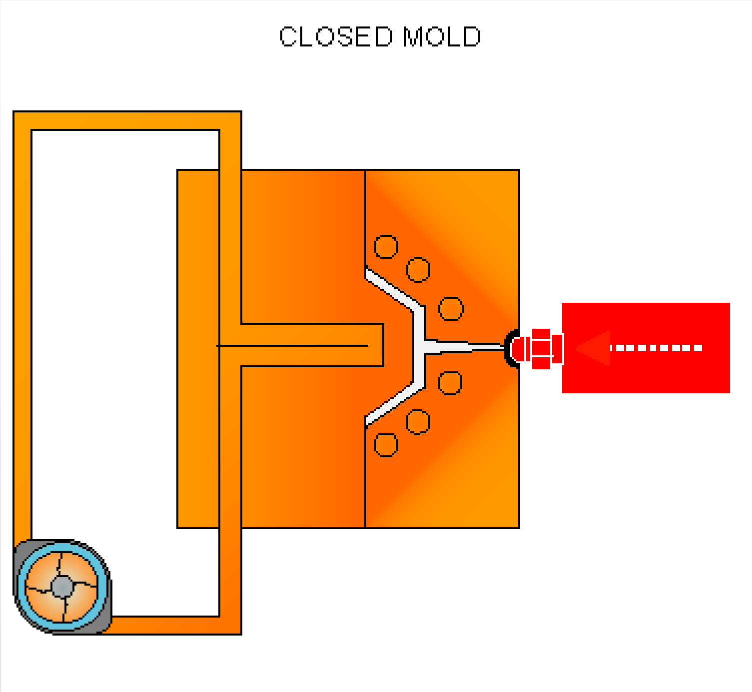




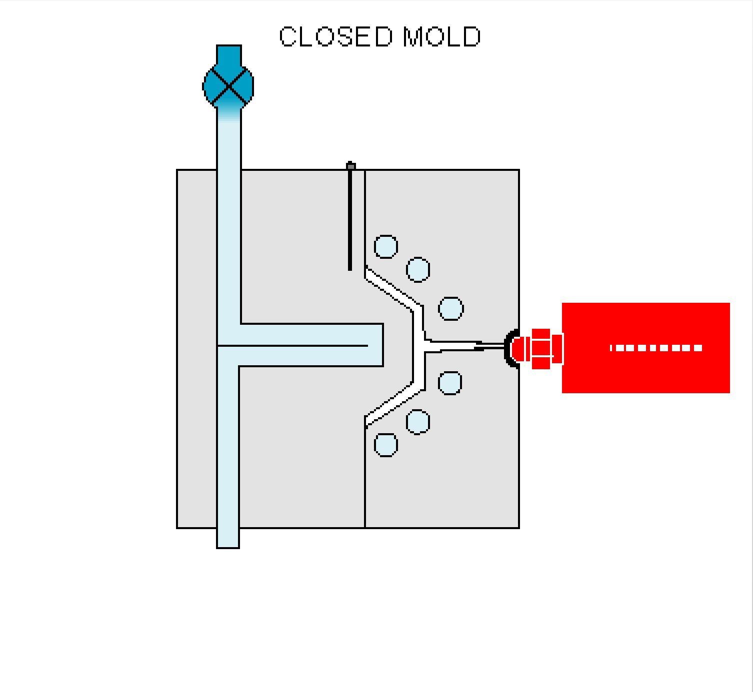
Problems with the Conformal Cooling Process

1. Complex 3 dimensional shapes place significant limits on the degree to which conformity can be achieved and the spaces between the channels are a source of variations in temperature.
2. The cooling circuits are still subject to the usual efficiency problems associated with coolant flow rates and heat extraction.
3. Corrosion and scale build up are even harder to deal with.
4. The problem of balancing multiple circuits is still inherent. Water temperatures and flow rates through each circuit still have to be tuned by trial and error to achieve uniformity.
5. Such molds also have a limited service life

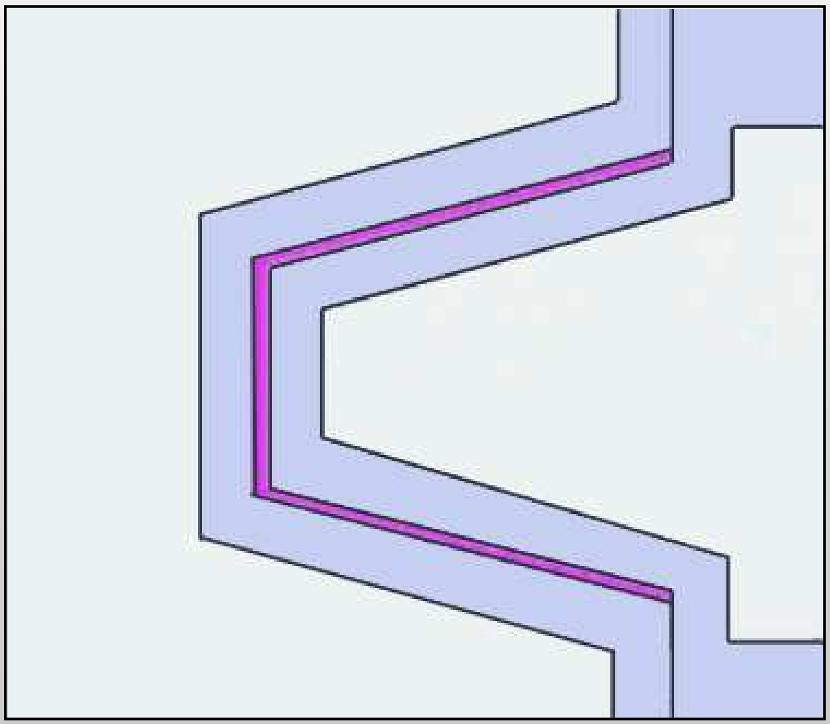
Conventional Cooling



Pulse Cooling



Now Consider "Shelling"



- 'Shelling' creates uniform heat flow paths through the die plates - ***BUT*** ………….

Problems with Shelling Applying Turbulent Flow

- Flowing coolant over the surface simply does not work.
- Coolant will follow the easiest flow path.
- Stable turbulent flow is unachievable.
- Dead spots will occur where inefficient cooling will reside.
- Volume flow requirements are very large.
- A significant portion of the coolant is simply not “working”.
- Mechanical robustness is of concern.

So, how can the ultimate GOALS of

EFFICIENT COOLING

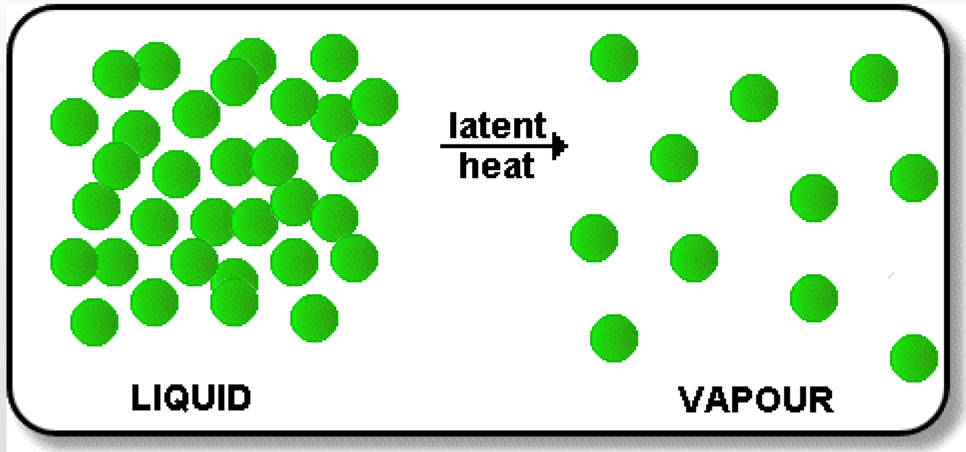
and

UNIFORM COOLING

be achieved?

Evaporative Cooling

Specific heat of liquid water, in calories, is 1.00 cal/g x ^{o} C.



The definition of the **specific latent heat of vaporization** is

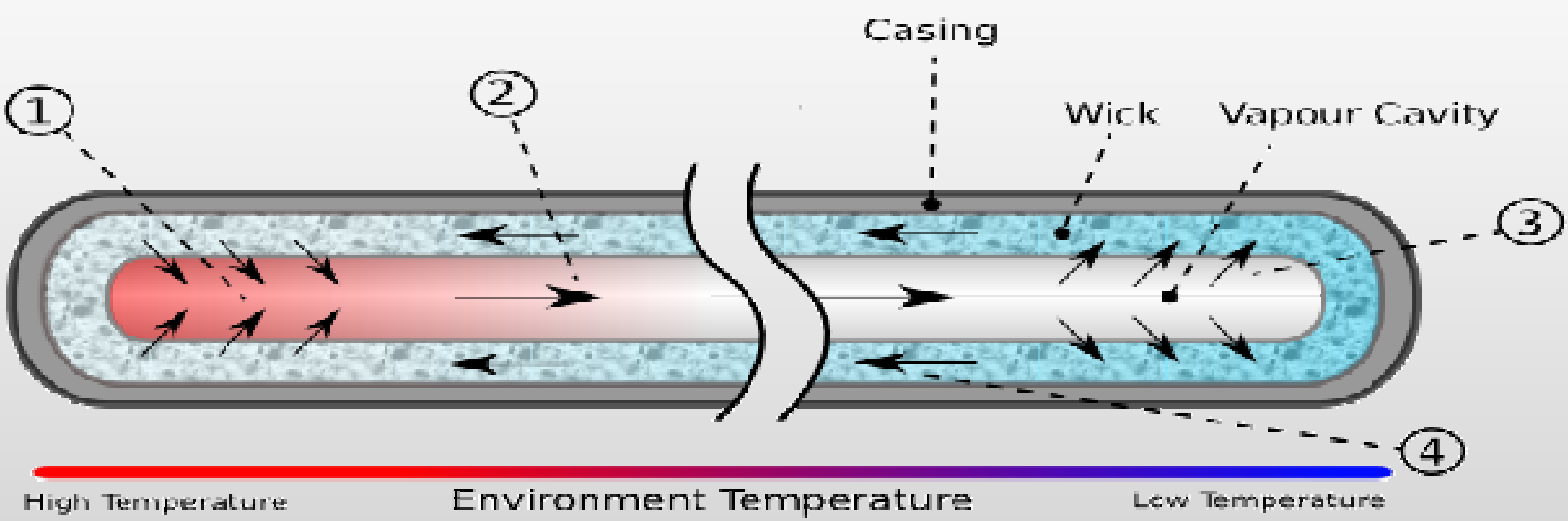
'The specific latent heat of vaporization is the amount of heat required to convert unit mass of a liquid into the vapor without a change in temperature."

For water at its normal boiling point of 100^{o} C, the latent specific latent heat of vaporization is 540 Calories/g. This means that to convert 1.00 gram of water at 100^{o} C to 1.00 gram of steam at 100^{o} C, 540 gram of heat must be absorbed by the water. Conversely, when 1 gram of steam at 100^{o} C condenses to give 1 gram of water at 100^{o} C, 540 calories of heat will be released to the surroundings.

Some values for specific latent heats of fusion and vaporization:

Substance	Specific latent heat of fusion $kJ.kg^{-1}$	? C	Specific latent heat of vaporization $kJ.kg^{-1}$	? C
Water	334	0	2258	100
Ethanol	109	-114	838	78
Ethanoic acid	192	17	395	118
Chloroform	74	-64	254	62
Mercury	11	-39	294	357
Sulphur	54	115	1406	445
Hydrogen	60	-259	449	-253
Oxygen	14	-219	213	-183
Nitrogen	25	-210	199	-196

Heat Pipe



Heat pipe thermal cycle

1) Working fluid evaporates to vapour absorbing thermal energy.
2) Vapour migrates along cavity to lower temperature end.
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy
4) Working fluid flows back to higher temperature end.

ABS	150 BTU/lb.	amorphous
PP	300 BTU/lb.	crystalline
PC	200 BTU/lb.	amorphous
HDPE	350 BTU/lb.	crystalline
PVC	80 BTU/lb.	amorphous

THERMAL K OF MOLD STEELS AND ALLOYS (@68xf)	
H13	14.2 BTU/FT*H*F
P20	16.7
SS304	8.6
CU	174.5
AL	87.7
BECU	77.3
TITANIUM	3.8
WATER	0.35 (standing/Laminar)
AIR	0.015

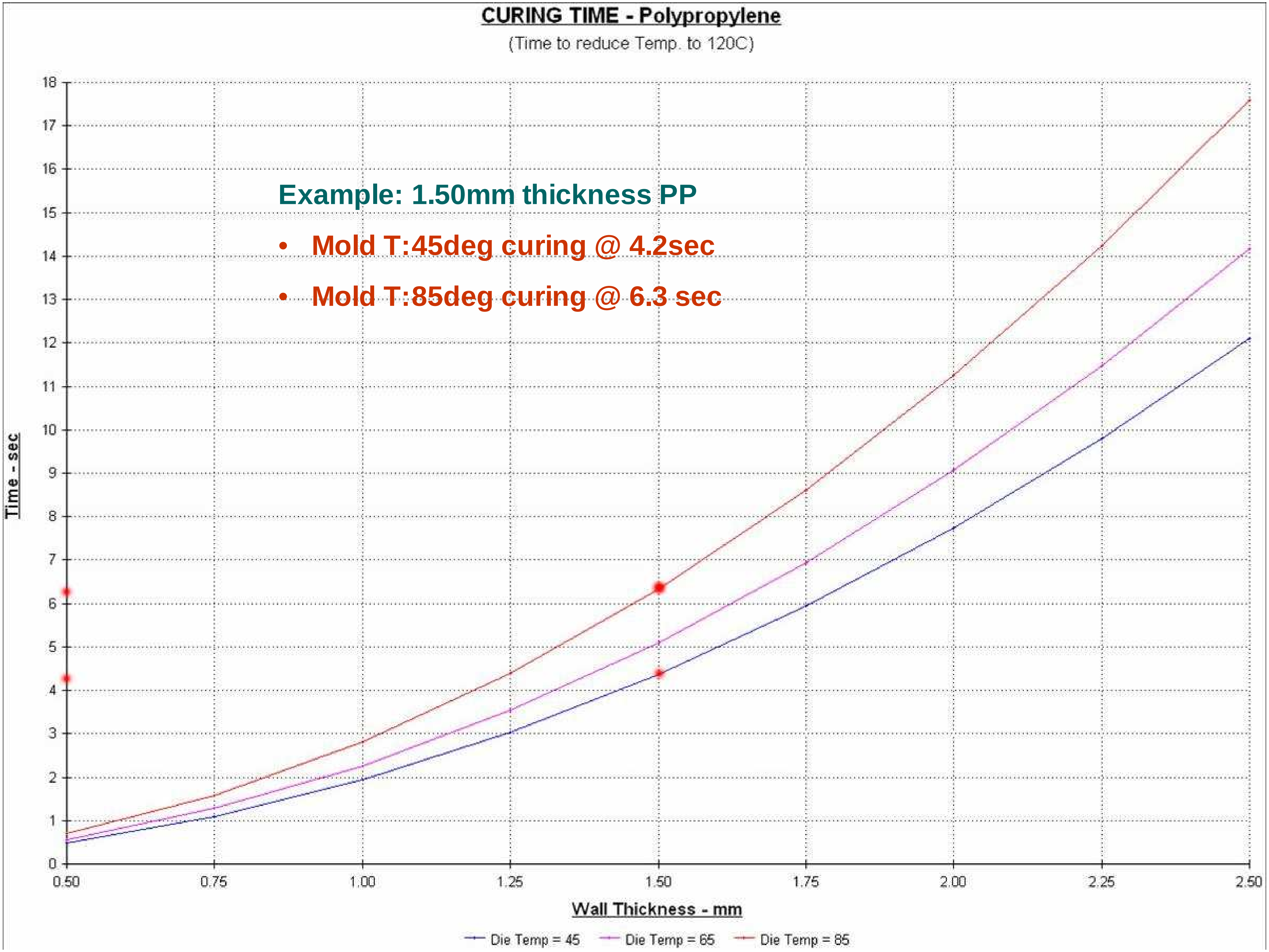
Figure 1: Optimum mold cooling

Mathematical Model

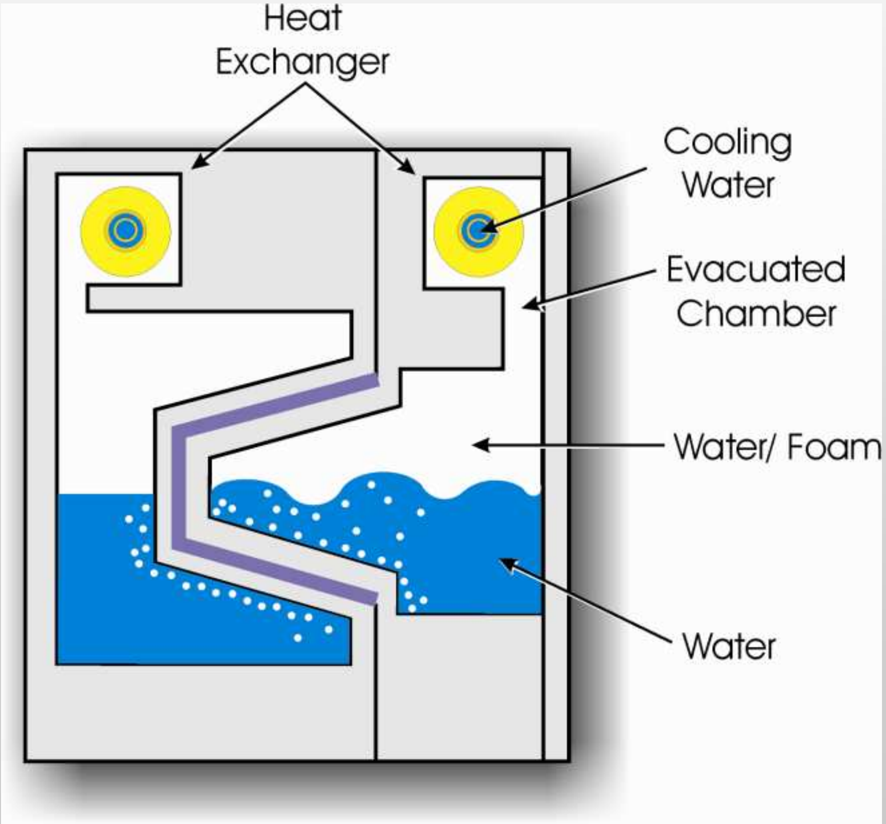
In the following graph, curing time is plotted against wall thickness for polypropylene mouldings'.

These times are only achievable ***IF*** the mold's cooling system is working both efficiently ***AND*** uniformly.

The effect of mold temperature on curing time is easy to see.

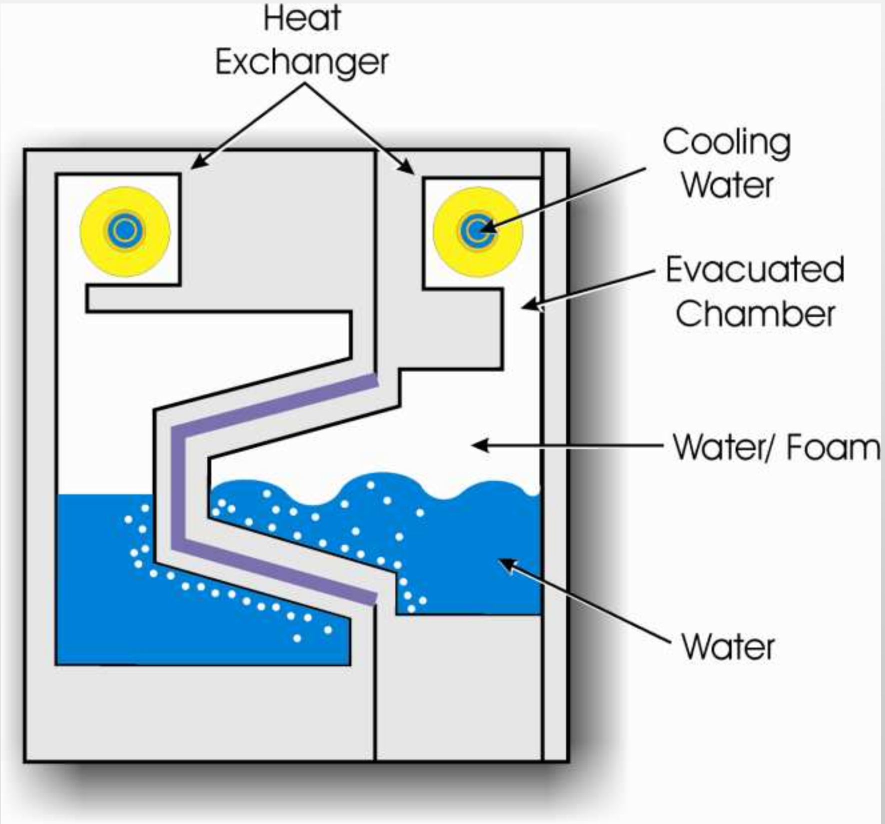

CURING TIME - Polypropylene
(Time to reduce Temp. to 120C)
Example: 1.50mm thickness PP
• Mold T:45deg curing @ 4.2sec
• Mold T:85deg curing @ 6.3 sec
Time - sec
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
Wall Thickness - mm
Die Temp = 45
Die Temp = 65
Die Temp = 85

Evaporative Cooling Solution



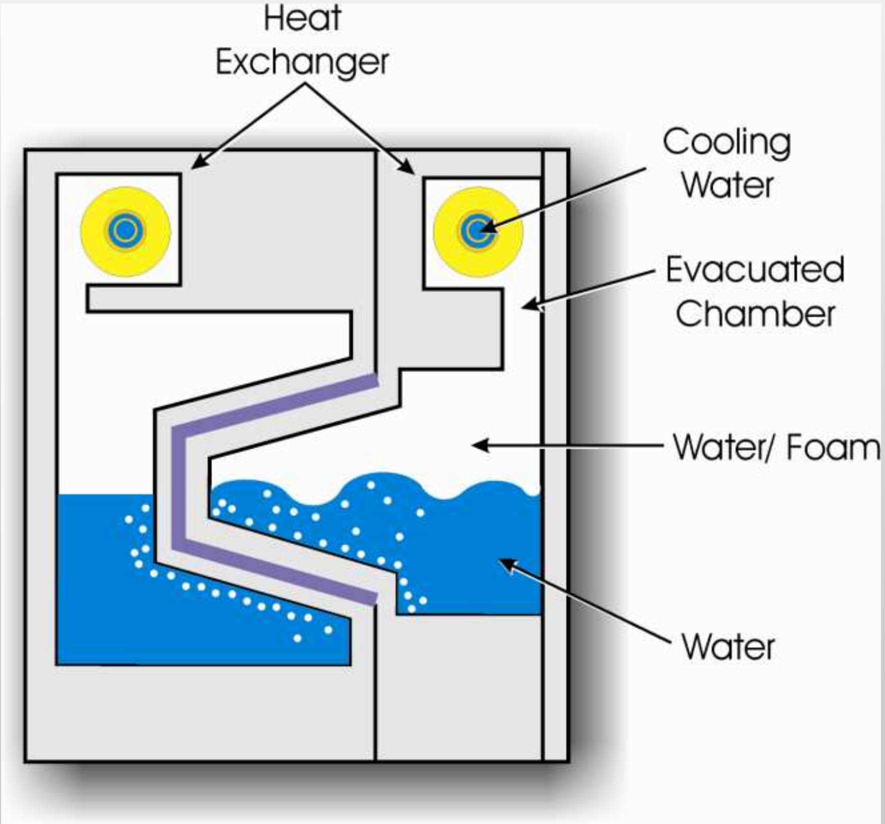
- Shelling combined with Cooling by Evaporation!!
- All air is evacuated from the 'Cooling Chambers'.
- This allows water to boil at very low temperatures.
- For example, at 10 mbar of pressure, the boiling temperature is less than 10^{o}C.

Evaporative Cooling Solution



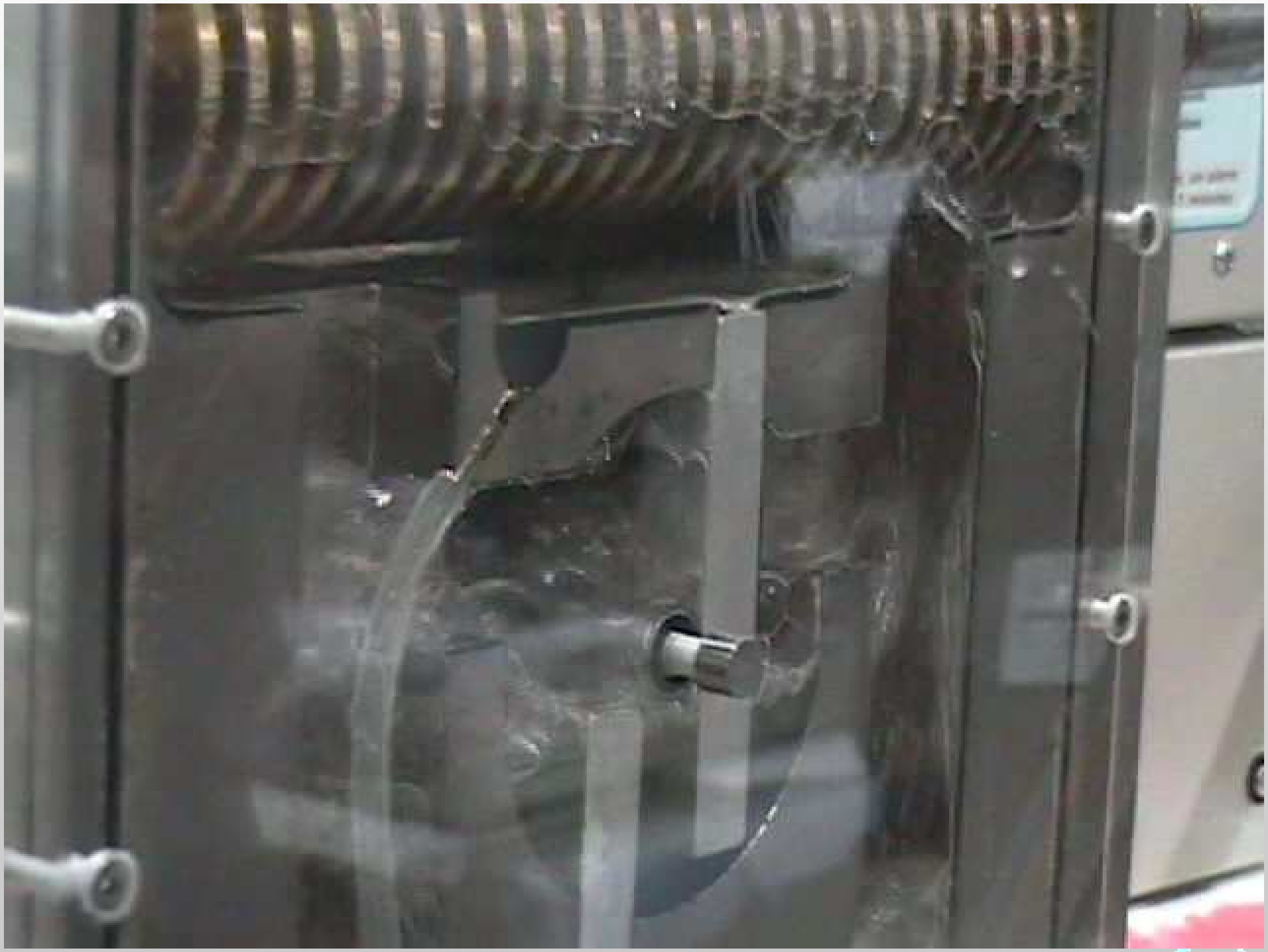
- Heat is extracted from the mould by converting it to latent heat of vaporisation
- ***This is an extremely efficient process!***
- The resultant vapour rises to the top of the mould where it is condensed by simple heat exchangers

Evaporative Cooling Solution



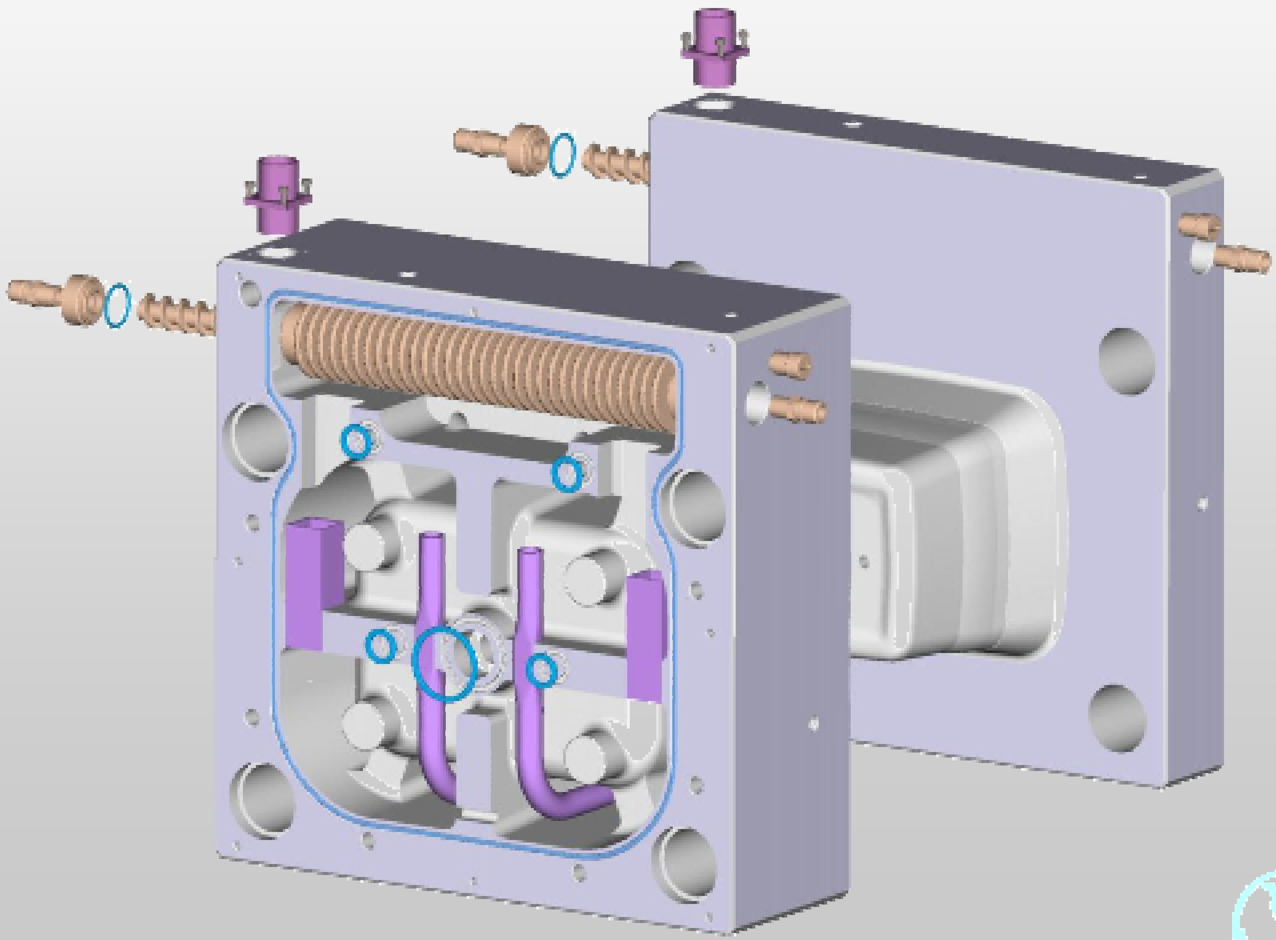
- The water will always boil where it is hottest and condense where it is coolest.
- This process ensures that the temperature profile throughout the mould is *automatically* evened out.

Evaporative Cooling Solution



Evaporative Cooling Solution

A Typical Evaporative Mold

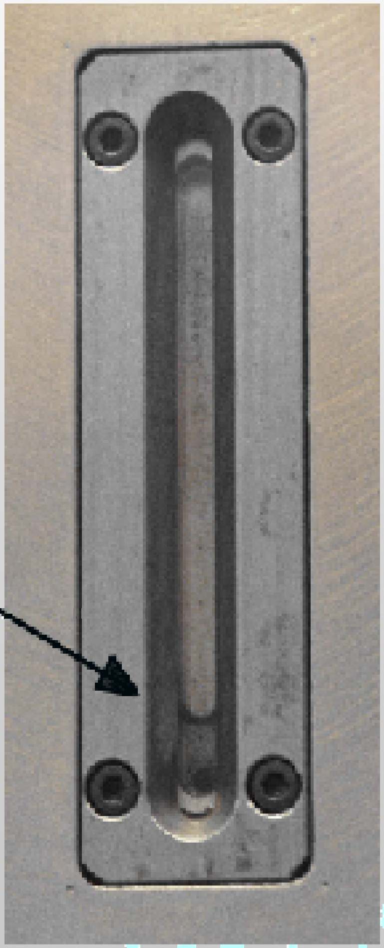


Closed Loop Control

- The temperature of the mould is controlled accurately and easily using the Ritemp™ mould Temperature Controller.
- This device turns the coolant supply on and off in response to the moulds temperature.
- When required, it can also control a heating element for preheating the mould.

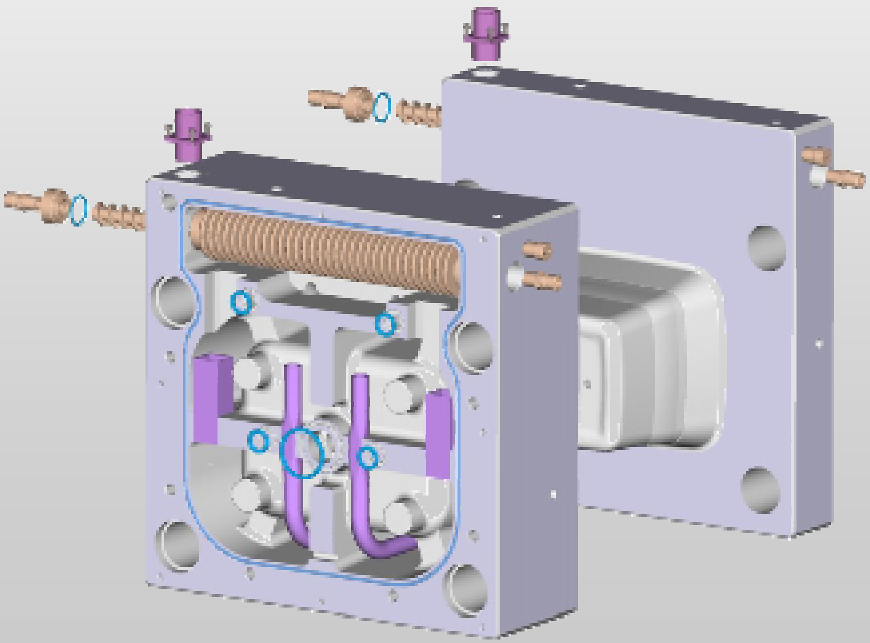
Sight Gauge

- A simple sight gauge is available for incorporation into the mold.
- If the water level in the gauge is in the right range then you know that the mold evacuation level is satisfactory.

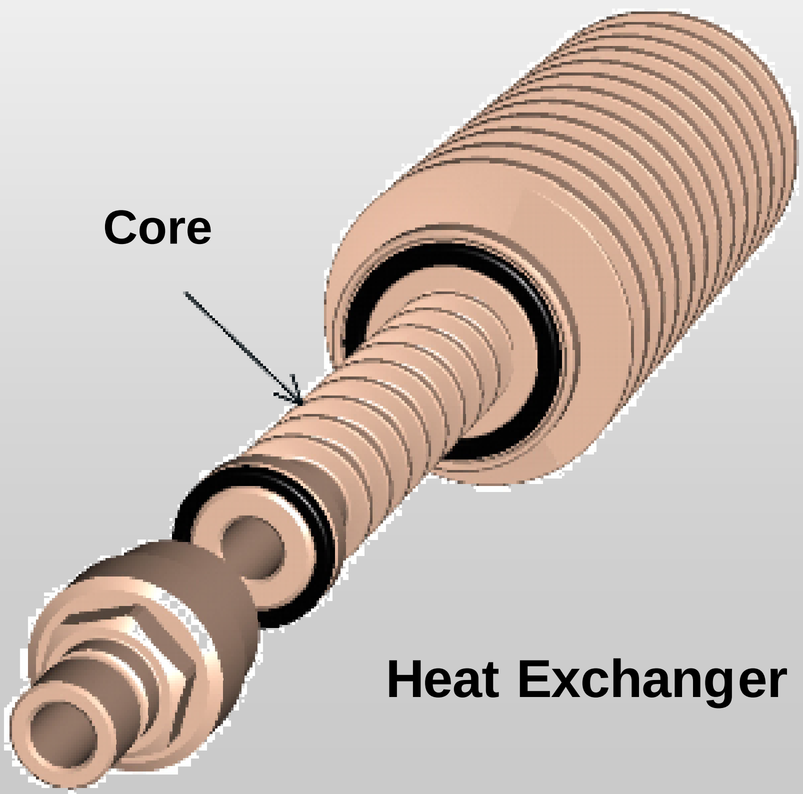


The Benefits

- Consistent, uniform mould surface temperature is achieved.
- The need for running multiple cooling circuits at different temperatures is eliminated.
- A significant "side" benefit is the minimization of corrosion from the cooling system.



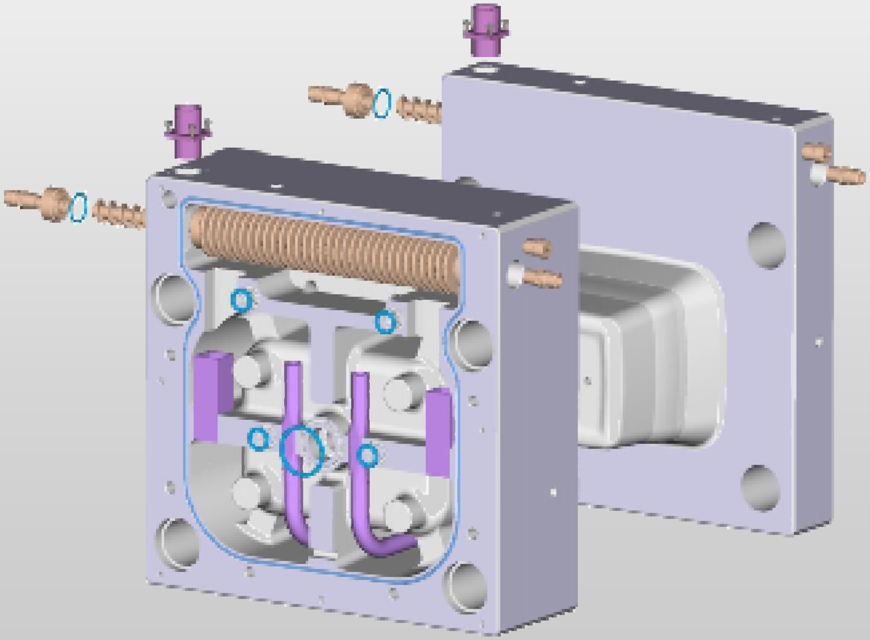
Corrosion is Minimized



- Since air is deliberately excluded from the cooling system, it is impossible for it to suffer from corrosion (conditional upon sustainable vacuum).
- The only vulnerable part is the brass core of the heat exchanger which is highly resistant to corrosion.
- This core is inexpensive and is easily replaced w/ standard components.

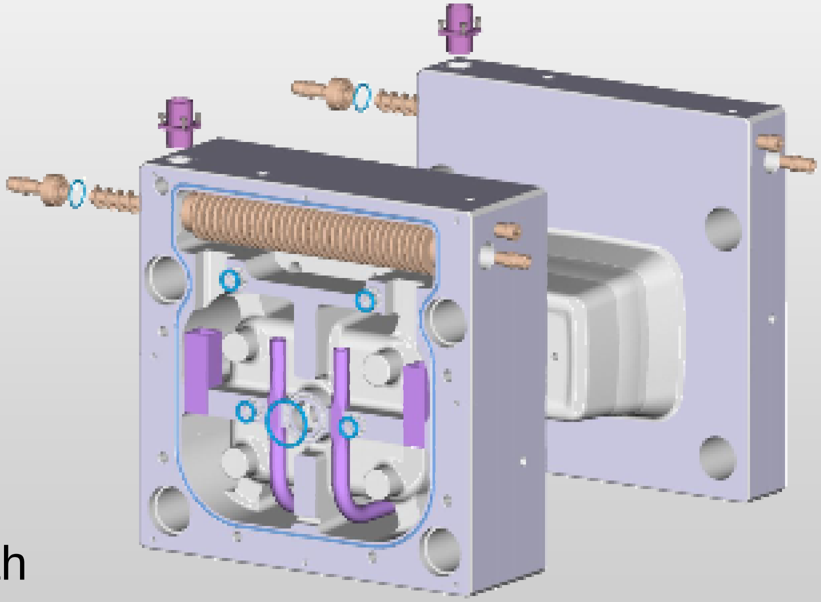
The Benefits

- The cooling chamber can be intersected by ejector pins so there is no need to compromise cooling due to their placement.
- The same principle applies to screws, slides, etc.
- Mould features are designed without compromise



Benefits Summary

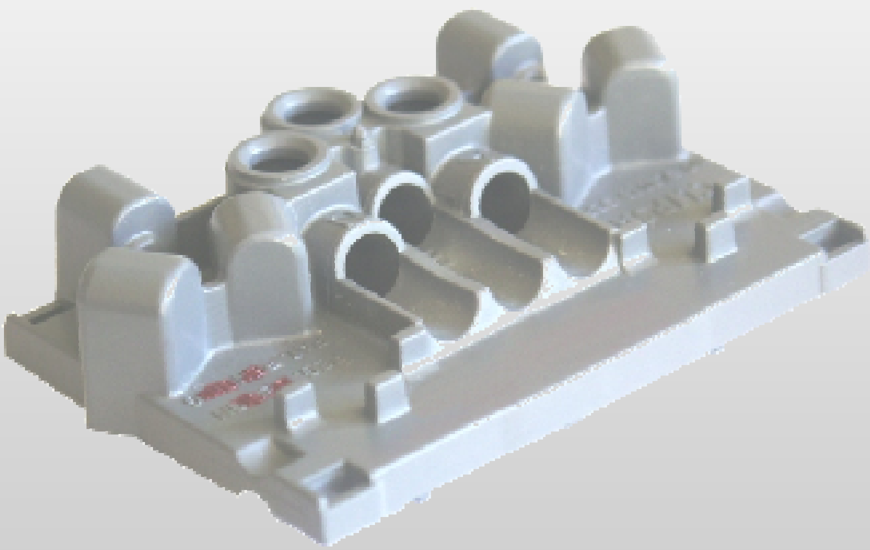
- Faster cycle times
- Lower Reject Rates
- Corrosion Minimized
- Reduced maintenance costs
- Improved Energy Utilization
- Reduction in CAPEX for future growth
- Reduced condensation and related issues



A Few Plastic Part Examples:

1. Technical Part: (cycle, design benefits)
2. Packaging application (cycle, maintenance benefits)

Technical Part: Cycle Benefits

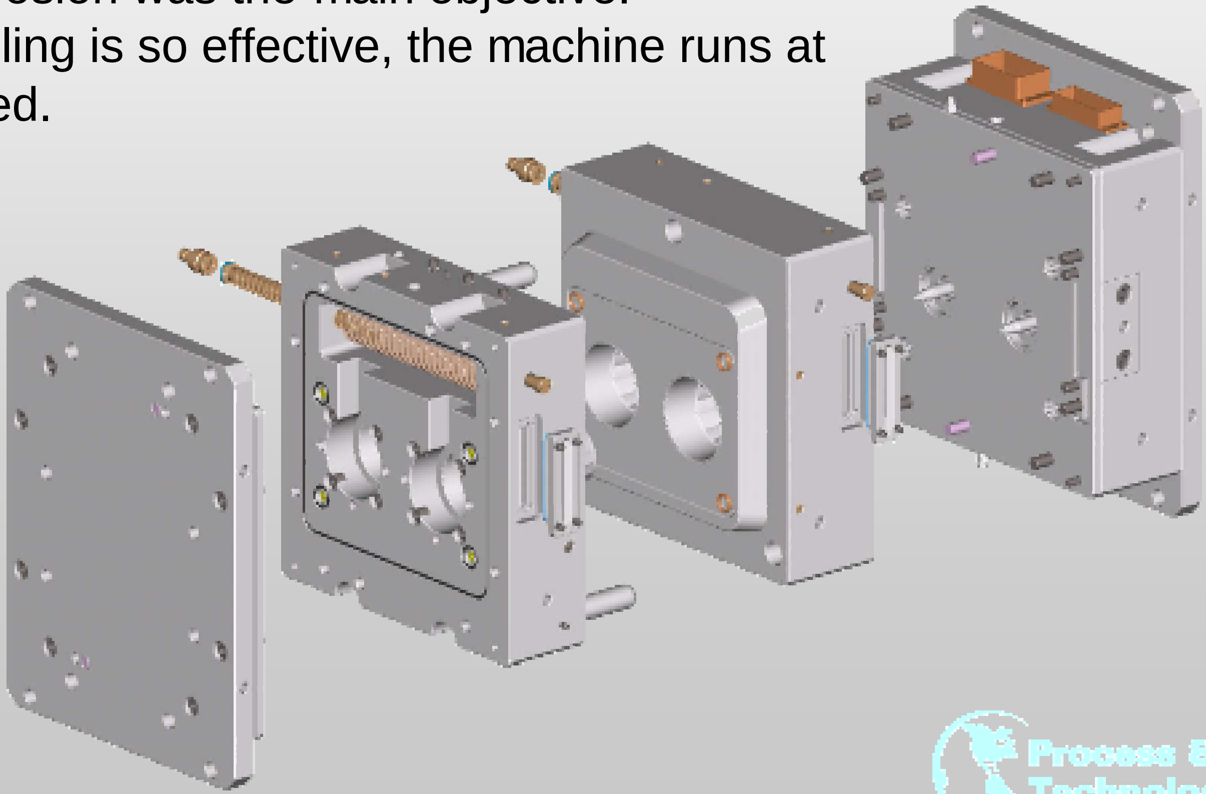


- Two molds were made - one with conventional cooling & the other with Evaporative Cooling Technology.

- The Evaporative Technology, *halved* (-50%) the cooling time.
- It produced identical parts **20% faster**

Packaging Part Application

- Elimination of corrosion was the main objective. However, the cooling is so effective, the machine runs at its maximum speed.



Evaporative Cooling molds always deliver the best possible cycle time!

Questions?