Perfect your process

A guide to temperature control in manufacturing processes

Second edition - now including flow control

TOOL-TEMP®

The Process Temperature Control Specialists

In the world of industrial temperature control, the Tool-Temp name is synonymous with innovation, outstanding build quality, long life and low maintenance. Tool-Temp offers a complete range of temperature controllers and water chillers - from small portable units for dedicated single-machine operation, to large multi-machine systems.

Contents

1 Introduction

This guide is intended to provide an introduction to the basics of temperature control, to help you get the most out of your equipment. It looks at Temperature Control Units (TCU's) & Chilling equipment, covering the main features of the different types within each group and gives a guide to the advantages and disadvantages of each.

It also covers the basic calculations needed in order to size the TCU or chiller correctly and some basic guidelines when connecting them to your process.

For example, many of the factors to be taken into consideration when looking at TCU's are overlooked in favour of getting the right kilowatt rating. This in itself is important, but there are other equally important factors such as flow rate and cooling capacity, which should also influence your choice of equipment.

Advantages of accurate temperature control 2

There are two areas which can be improved through accurate temperature control; quality and cycle time.

Quality can be improved greatly in mouldings by having a controlled mould temperature. Correct temperature provides optimum surface finish, dimensional stability through control of shrinkage and improved physical properties by reducing in-mould stress.

Improvement in product quality equals:

- lower scrap/production costs
- lower return costs
- happier customers
- more repeat business

Cycle times can be improved by having a temperature controller with greater cooling capacity and flow rate coupled with improved mould connections/flow.

Reduced cycle time equals:

- lower running/energy costs, which leads to increased profit, which can allow you to be more competitive!
- increased available production capacity.

Tips on how to improve your temperature control will be explored later in the book

3.1 Types of temperature controller – cooling

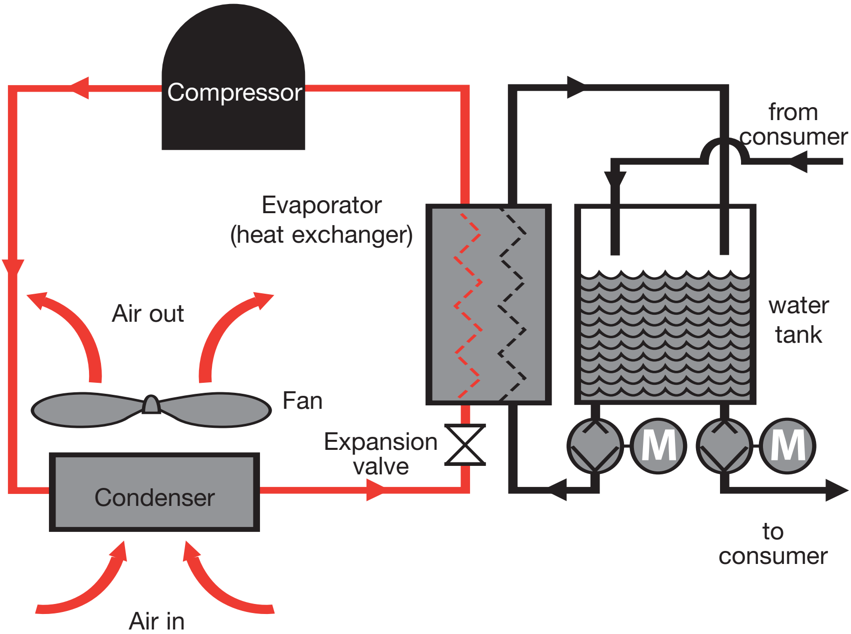
Temperature control falls into two broad categories: cooling and heating. However, there is a lot more to it than that. There are several different types of controllers which heat and/or cool and some that do a combination of both.

Water Chillers

Chillers are perhaps the most common and accurate method of water cooling in use. In simple terms, chillers compress a refrigerant gas which in turn cools a water circuit or tank via an evaporator or heat exchanger. Most common is the air-cooled type of chiller which needs a good flow of cool air available. Water cooled chillers use an alternative source of water (tower or mains) to condense the gas. They are ideal in small confined spaces where there is little air flow or the ambient temperature is too high. Chillers are a good all round solution that can be used to cool hydraulics, temperature control units (TCU's) or directly through the mould due the low temperatures which can be achieved.

Advantages	Disadvantages
Low Temperatures made possible by refrigerant circuit	Initial cost
Exact temperatures possible due to control of circuit	Air cooled models can increase ambient temperature if inside
Closed system, therefore no anti-bacterial chemicals needed	

Water Chiller Schematic



In addition to the above, there are small mobile chillers available which also have a heating capability, e.g. the Tool-Temp TT5000H which cools as a normal chiller but also has 6kW heating power available. These types of machines allow a process to come up to temperature prior to running if, for example the ambient is slightly lower than the running temperature in the winter.

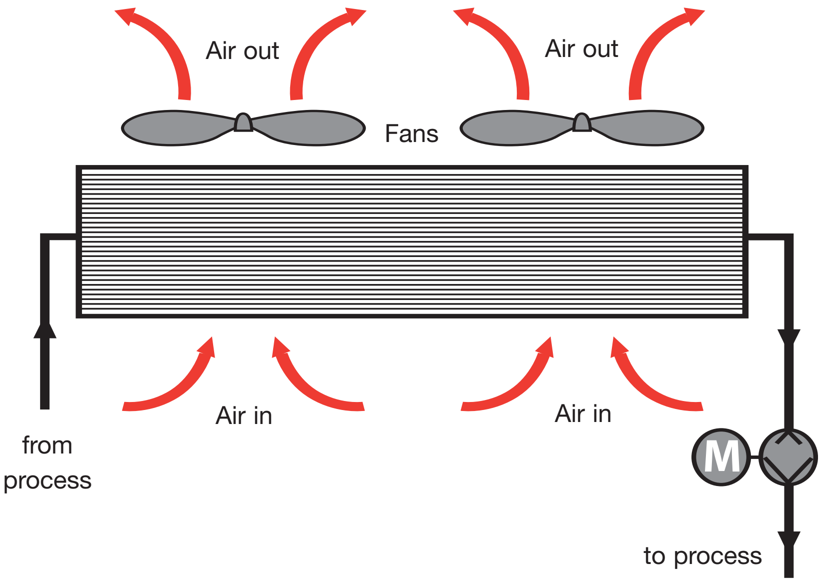
3.3 Types of temperature controller – cooling

Air Blast Coolers

With Air Blast or ‘Free Cooling’, fans force ambient air over many small pipes in order to reduce the water temperature, generally very similar to the way a car radiator works but larger in scale. This method is ideal for hydraulic cooling only, for control of TCU’s or any application where cooling is required but a fixed, low temperature is not essential.

Advantages	**Disadvantages**
Low running costs. Power is used only to drive cooling fans	Water temperature is generally just above ambient
Closed system	

Air Blast Cooler Schematic



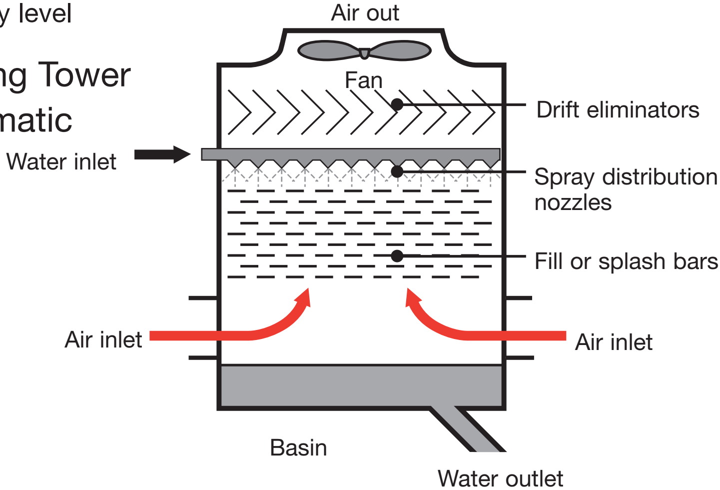
Cooling Towers

Warm water returning from the process is sprayed down into the tower, giving up heat to the air circulating through the tower. In addition to this heat transfer, the energy used to vaporise some of the water also reduces the temperature. Towers are still in use, but rarely specified when installing new cooling systems nowadays due to the high maintenance costs associated with an open system and the related risks of legionella bacteria.

Advantages	**Disadvantages**
Low running costs	Water temperature is generally 3 - 5°C above wet bulb temperature*
Slightly lower water temperatures than an air blast system	Open system which can form legionella, requires rigid maintenance program (chemical additives)

*Wet bulb temperature - a measure of the dry air temperature and humidity level

Cooling Tower Schematic



4.1 Types of temperature controller – heating

Standard Water Temperature Control Units (TCU's)

Standard TCU's are open tank systems which can control water temperature up to 90°C.

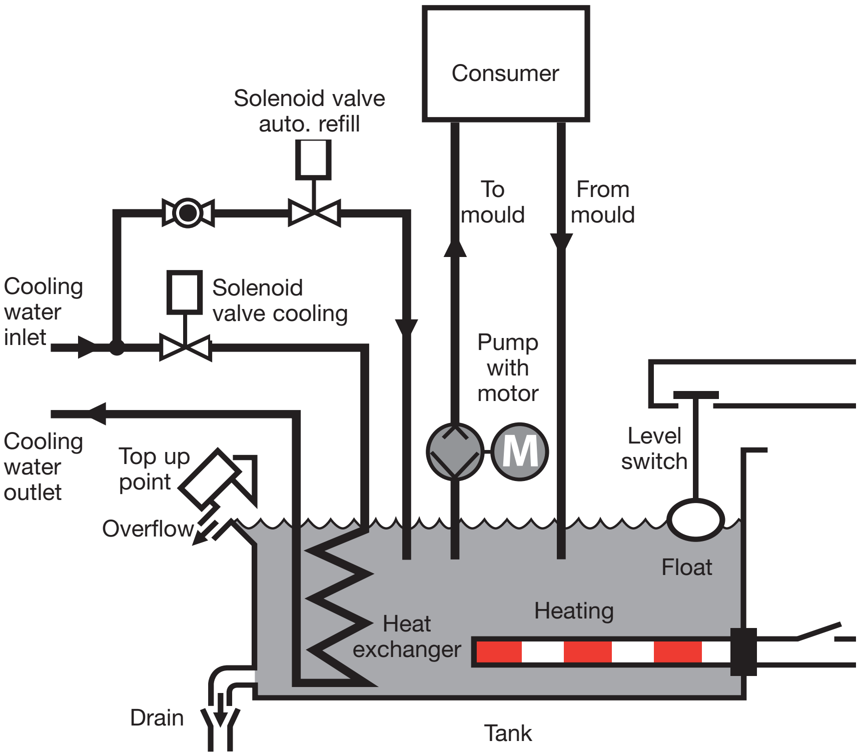
TCU's heat water to a running or production temperature and are commonly judged by their kW rating, i.e. the higher the kW, the faster the heat-up time. However, once up to temperature they can also cool as well as heat, hence the term "temperature controller" rather than just "heater". Cooling can be either direct or indirect.

Direct cooling is where the cold water is introduced directly to the tank and hot water is basically dumped to drain or the central cooling system. This system is a little crude but can be good for lower temperatures.

Indirect cooling is where the cooling is provided via a heat exchanger (coil, plate or shell and tube type). Indirect cooling is the most common type used in the industry as there is a greater level of control. A high capacity plate heat exchanger for example, can be used as opposed to a direct cooled unit to give a low temperature with but with the added control of an indirect unit.

Advantages	**Disadvantages**
Relatively low cost of equipment	Low temperature range
Low cost of heat transfer medium (water!)	Potential corrosion from untreated water in mould in (as opposed to oil)
No mess in the event of spillage	Potential Calcification
Efficient heat transfer	

Standard TCU Schematic



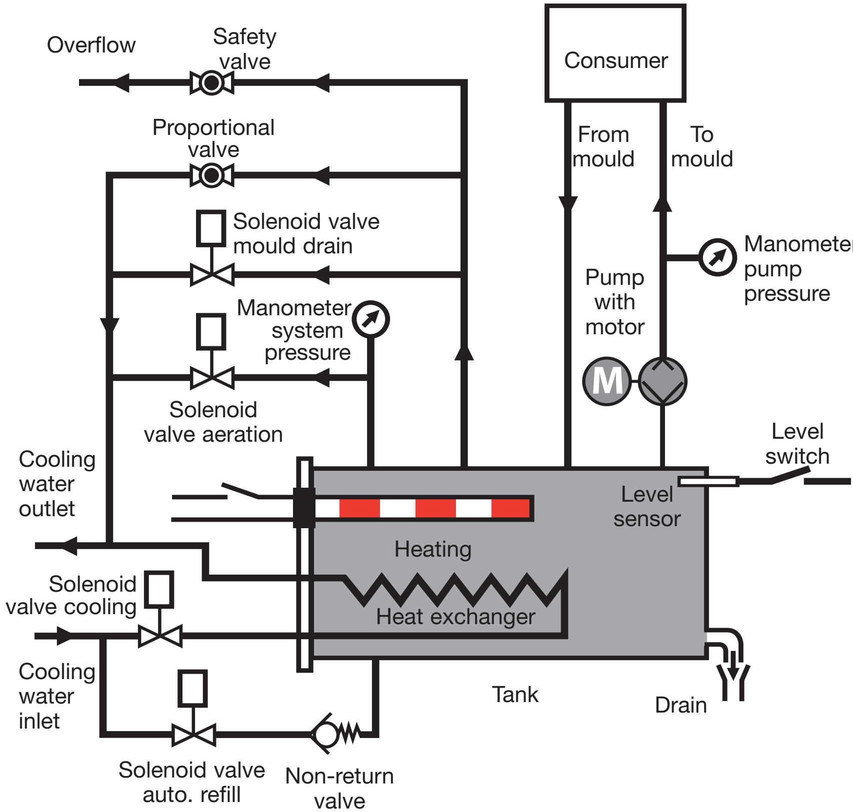
Pressurised TCU's

Pressurised TCU's are closed tank systems which can control water temperature up to 140°C. (or 160°C in special models) When under pressure, water can remain in liquid form at temperatures well above 100°C. A pressurised TCU will become a closed system once the temperature reaches 85°C, thus creating a pressure within a sealed tank with a fixed volume of air and water. As the temperature increases, the pressure on the water increases allowing temperatures of up to 140°C without boiling (or 160°C) Because of these high pressures, significant safety features must be included within the unit, as well as improved pipe work to and from the medium.

Again, these units both heat and cool depending on the demand at the consumer.

Advantages	**Disadvantages**
Higher Temperature range	Not as high a range as oil
Low cost of heat transfer	Need to upgrade pipework in most medium cases
Efficient heat transfer	Initial cost higher than standard units

Pressurised TCU Schematic



4.5 Types of temperature controller – heating

Oil Heaters

Using oil as a heat transfer medium allows you to run at much higher temperatures. This can be useful for moulding high temperature engineering polymers, as well as die-casting, chemical, textile and laminating processes. However, it has to be remembered that heat transfer oil is expensive, can be messy and also doesn't transfer heat quite as well as water (approximately 1/3 as efficient).

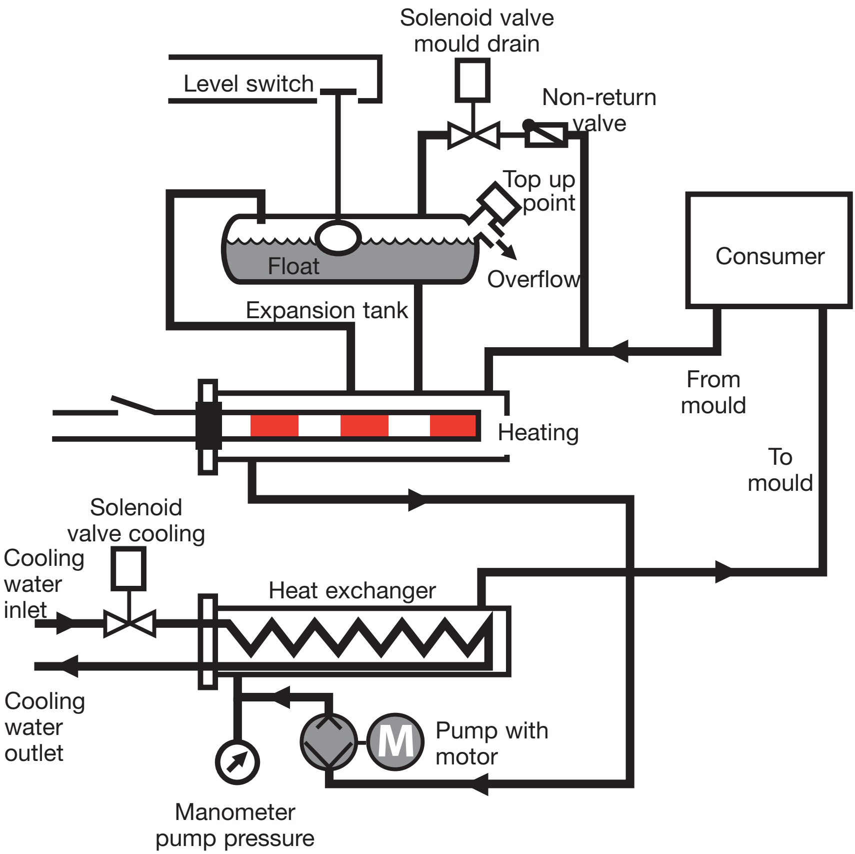
In an open system, mineral heat transfer oils can run at up to 150°C.

In a closed system, that temperature can be increased to around 250°C.

Synthetic heat transfer oils, e.g. Marlotherm, can be run at up to 360°C using the Tool-Temp TT380 oil heater.

Advantages	**Disadvantages**
High Temperature range (up to 360°c)	Initial cost
No Calcification	Less efficient heat transfer than water
No Corrosion	Cost of heat transfer medium
	Needs regular maintenance (i.e. oil changes)
	Mess in the event of a leak

Oil Heater Schematic



4.7 Additional features of TCU's

'Vac' or Leakstopper

This feature runs the pump in reverse in the event of a leak developing at the mould. The water is then 'vacuumed" around the mould allowing you to finish your production run in an emergency. Please note that the negative pressure will not be equivalent to the positive pressure, therefore flow rate may be compromised.

Mould Drain

This feature returns the water or oil back to the tank in the temperature controller. A handy feature prior to mould changes.

Audible Alarm

Speaks for itself - an alarm that sounds in the event of a failure in the system.

External Thermocouple

Connecting an additional thermocouple to the TCU allows you to monitor the temperature at the process or consumer rather than the tank of the TCU.

Interface

This allows the TCU to communicate with the moulding machine (providing the machine has the necessary hardware and software) and can be either digital or analogue (hard-wire). There are also various protocols used - contact PTA for further details.

Flow control

This feature is now standard on all TCU'S and is already integrated into the temperature control unit. The flow rate is shown directly on the temperature controller.
Should the flow rate be suddenly reduced to under the minimum acceptable level, an alarm is automatically activated. Both alarm and red indication lamp draw the attention of the user to the fault and they can then investigate the problem.
The minimum acceptable level is automatically calculated by the unit at the start of operating. However should the user prefer to define a minimum acceptable level; a manual mode can be activated.

The Tool-Temp flow control can work with all types of fluids: water, oil, polyglycol, etc. and temperatues upt 360°C.

5.1 Calculating heat loads

Calculating the heat load for a mould allows you to choose the correct kW rating for your temperature controller. For this, you need the following information:

A – mass of the mould or consumer being heated (kg)

B – Specific Heat Capacity (SHC) of the material of the mould (kCal/kg/°C)

C – Target temperature of the mould. (°C)

D – Initial temperature of mould (or ambient) (°C)

You can then apply the equation below to the above values;

Heat required = A x B x (C - D)

(C - D also known as ΔT or delta T, the difference in temperatures) As the SHC of the material is expressed as kCal/kg/°C, this gives us an answer in kCal. 860 kCal = 1kW, therefore the kCal figure can be divided by 860 to give an answer in kW. Hence the full calculation is;

Heat Required (kW) = (A x B x ΔT) ÷ 860

Example

To calculate the heat required to take a 400kg steel mould to 80°c from an ambient of 20°c, the equation is as follows;

A – mass =400kg

B – SHC of steel is 0.112 kcal/kg/°c

C – ambient = 20°C

D – desired temperature = 80°C

Therefore:

kW required = (400 x 0.112 x 60) ÷ 860

= 3.13 kW

Safety Factor Note

Killowatt ratings are based on an 1 hour timescale. This means that 3.13 kW will heat the mass to the desired temperature in 1 hour. Therefore, theoretically, a 9kW heater will heat the mould up in just over 20 mins. However, this equation does not take into account any heat losses through the pipes and the tool, or any potential losses to the platens or other adjoining equipment. It is therefore quite common to build in a safety factor of 1.2 to compensate for any such potential losses.

6.1 Calculating cooling capacities

Cooling capacity calculations are necessary not just to size chillers properly, but also to ensure that mould temperature controllers have adequate heat exchangers. The following information is required:

A = Material throughput (kg/hr)
B = SHC of material (kCal/kg/°C)
C = Melt temperature (°C)
D = Mould temperature (°C)

As cooling capacity is generally expressed as kCals, there is no need to change to kW. Therefore the calculation is simply;

Cooling required (kCal) = A x B x (C – D)

Example

We require to cool 40kg per hour of Polypropylene being processed at 210°C with a mould temperature of 15°C

A = 40 (kg/hr)
B = 0.48 (kCal/kg/°C)
C = 210°C
D = 15°C

Therefore:

Cooling capacity (kCal) = 40 x 0.48 x 195

= 3744 kCal

Hydraulic Cooling

To calculate the cooling required for hydraulic oil in Injection Moulding machines, you need to following very simple calculation;

Motor size (kW) x 35% x 860 = Cooling required (kCal)

If using older, less efficient machines or machines with particularly fast cycle times, it may be necessary to increase to 50% of motor size.

Additional Chiller Notes

Make sure you always check the mould temperature required and reference it against the rating of the chiller you are considering. Eg. All Tool-Temp chillers are rated at 15°C. Should you wish to run at 10°C, you must refer to the relevant data sheet for the cooling capacity at 10°C as it will be less than the capacity at 15°C.
If hot runners are used, they can have a significant affect on the cooling capacity required. Always refer to your local technical representative (details in section 10) for help and advice in selecting
the correct chiller model.

7.1 Mould connections

The calculations explained on the previous pages are a good basis upon which to specify the best equipment for the job. However, there is another important factor to be taken into consideration: the mould itself. There are two critical features of the mould, which in most cases, cannot be quantified. These are:

How efficient a heat exchanger is the mould? (bearing in mind that it is used to convey the heat away from the material and towards the water)

and:

What flow rate of water can I get through the mould?

The answer to the first point is one that you will struggle to find the answer to - either from moulders or tool designers. Let's just hope that they made the necessary number of channels, at the appropriate sizes and close enough to the mould surface to allow efficient heat transfer.

Now that flow control is standard on the units we are able to look at flow variations and the effect this has on the process.

Let's look at the traditional method first - as shown in the diagram opposite.

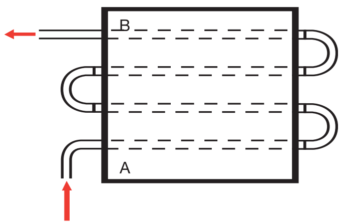
Why Flow Control?

A correct flow improves and maintains the quality of your parts. With the flow control of Tool-Temp there will be no problem with blocked pipes, closed valves or problems at the process end that are not visible. The unit will automatically inform the user about any reduction in the flow and therefore save money by reducing the manufacture of out of tolerance parts.

Looking at the following two methods shows examples of you can further enhance flow rates.

Traditional Method

In addition to what is shown below, the water outlet at point B is often fed to the other half of the tool and the pattern above is repeated.



During production, the mould will pick up heat. With this method, point B will have a temperature higher than point A. This is because the potential flow rate of the temperature controller isn't being used.

You may only be getting 10 l/min through the mould. However, if you adopt a more efficient set up, this flow rate could increase dramatically and the cooling effect with it.

Using the cooling calculation we can examine the potential cooling capacity. Assume there is a delta T of 5°C in the water inlet Vs outlet.

7.3 Mould connections

Manifold Method

When this more efficient method is adopted, it may be possible to significantly increase the flow rate.
If the Temperature Control Unit has a 1/2” outlet, forcing the water through one channel of only 1/4” will compromise efficiency. 4 channels of 1/4” have the same cross sectional surface area as 1 x 1/2” bore.

Therefore you can theoretically* get 4 times as much flow though the mould using a manifold with 4 x 1/4” outlets in this example.

*Assuming the pump has the capacity to support this

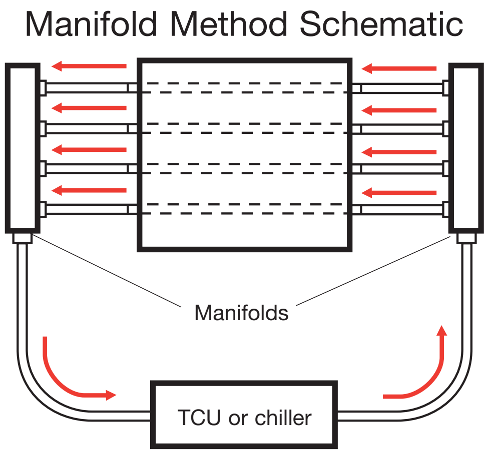
Now lets look again at the cooling calculation:

Throughput = 40 l/min = 2400 l/hr = 2400 kg/hr

SHC = 1

Δ T = 5°C

Cooling capacity = 12,000 kCal



Your process may not need the full capacity gained but you may be able to optimise your cycle time and also have a more even tool temperature. It's worth remembering that although in theory, a TT-157 mould temperature controller may be sufficient for a particular job, what if a TCU with a higher pump output (e.g. TT-133) was used and the above principals were put to the test? Would you be able to reduce your cycle time on a job that takes ages to cool in the mould?

Additional notes on connections

Quick release couplings can be a good idea in terms of mould changes but can restrict the water flow - especially the auto-shut-off types - so avoid if possible. Leakstoppers will not work using auto-shut-off fittings.

Specific Heat Capacity (SHC) guide

Material	SHC in kCal/kg/°C
Steel	0.11
Aluminium	0.21
Cast Iron	0.11
Brass	0.09
Copper	0.09
Water	1
Oil	0.5
ABS, PP, PBT	0.48
PA 6	0.38
PA 6,6	0.38-0.66
PC	0.24-0.29
HDPE	0.53
LDPE	0.6
PET	0.39
POM	0.36
PMMA	0.35
PS	0.29-0.5
PSU	0.29
PTFE	0.29-0.34
PVC	0.29
Rubber	0.38-0.48
SAN	0.29-0.53

NB These values are a rough guide only and may vary depending on the grade of material. Always refer to the manufacturers data sheet.

Material processing temperature guide

Material	Mould temp °C	Melt temp range °C
ABS	40 - 80	230 - 270
PP	10 - 60	180 - 250
PBT	60 - 90	250 - 280
PA 6	40 - 60	230 - 290
PA 6,6	40 - 60	280 - 300
PC	70 - 110	260 - 310
HDPE	5 - 40	180 - 250
LDPE	5 - 40	170 - 240
POM	40 - 100	180 - 220
PMMA (Acrylic)	50 - 80	210 - 250
PS	10 - 50	180 - 250
PSU	120 - 160	300 - 360
PVC	20 - 60	170 - 210
SAN	40 - 80	200 - 260
PEEK	160 - 215	370 - 400
PPO	80 - 105	250 - 300

NB These values are a rough guide only and may vary depending on the grade of material. Always refer to the manufacturers data sheet

8.3 Material reference tables and calculations

Bulk density guide

Material	Bulk Density (kg/m^3)
Steel	7878
Stainless Steel	10657
Aluminium	2691
Brass	8250
Copper	8906
Cast Iron	7208
Water	1000
Oil	897

Other useful conversion factors

°C = (°F-32) x 5 ÷ 9

°F = °C x 9 ÷ 5 + 32

1 bar = 14.4 PSI

1 kW = 860 kCal

1 kCal = 4 BTU

1 kjoule = 1 BTU

1 HP = 0.75 kW

1 lb = 0.45 kg

1 gallon = 4.54 litres

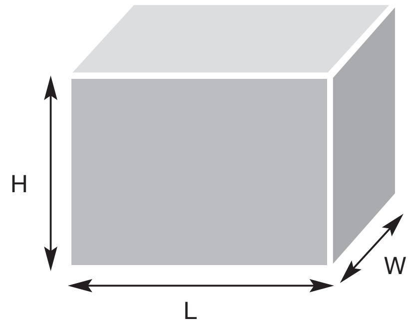
1m^3 = 1000 litres

1 inch = 25.4 mm

Calculating weight/mass

Cube

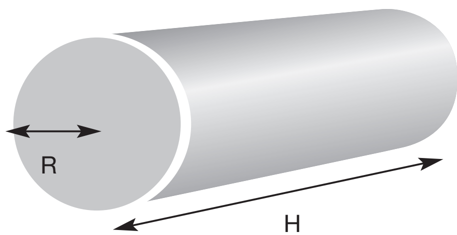
Weight/mass of a cube = L x W x H (metres) x bulk density of material (kg/m^3)



Cylinder

Weight/mass of a cylinder = πR^2 x H x bulk density of material (kg/m^3)

$\pi = 3.1416$



NB if calculating the weight of a hollow cylinder, perform the calculation for the whole radius, and then again using the radius of the hollow. Then subtract the hollow ‘mass’ from the whole ‘mass’.

9 Contact details & services

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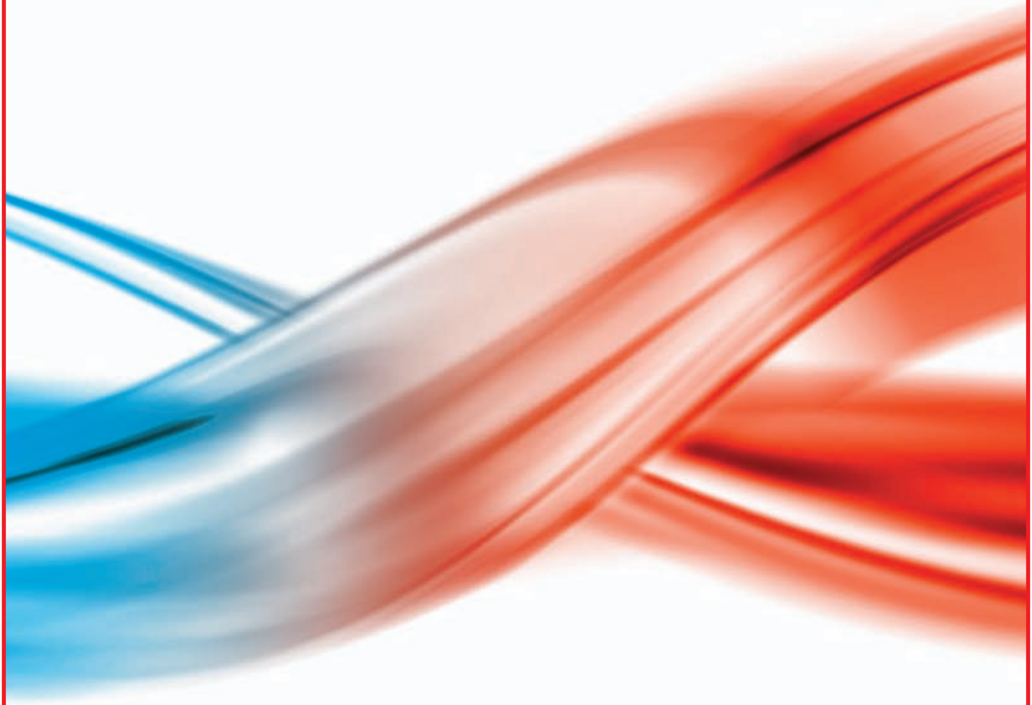
- Consultancy and system design expertise
- Ongoing maintenance and technical support
- Comprehensive UK stocks of genuine Tool-Temp spare parts



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