1

Troubleshooting Methodology

1.1 Troubleshooting

Troubleshooting is problem solving. Molding troubleshooters are called upon to resolve problems with the part, mold, machine, or process. There are many problems encountered in injection molding including these general categories:

- Cosmetic defects
- Dimensional problems
- Part breakage
- Long cycle times
- High scrap rate

All of the above lead to increased cost to manufacture a molded part, which often makes the difference between profit and loss. A molding operation that is consistently running high scrap or long cycles is going to struggle to succeed.

1.2 What Makes an Effective Troubleshooter?

The role of a troubleshooter is to find the root cause of a problem and do what is necessary to resolve the problem. Effective troubleshooters will look beyond their initial impressions and ensure that the true root cause has been addressed. Good troubleshooters take a great deal of pride in having the perseverance to solve a problem and ensure that it does not reoccur.

The Merriam-Webster dictionary defines a troubleshooter as:

A skilled worker employed to locate trouble and make repairs in machinery and technical equipment.

A person skilled at solving or anticipating problems or difficulties.

Troubleshooting is a skill that can be learned and this book is intended to help convey some of the knowledge that the authors have learned through many years of troubleshooting. Some of the key things that will help anyone improve at troubleshooting include:

- Willingness to listen to others. Anyone can provide the crucial piece of information that helps solve a problem. A good troubleshooter will listen to people.
- Being observant. A good troubleshooter will always be looking for what might have changed. Good observation skills are critical to troubleshooting. Good troubleshooters live by the motto “show me” rather than trusting that things have been set up correctly. Anyone who has spent time troubleshooting will tell you that there are plenty of cases where they were told that the material was dry or the mold was clean but verification showed otherwise.
- Willingness to learn. Many times when working on a problem a troubleshooter will have to dig deep into a subject to learn what the root cause really is. Be open to learning and use all resources available to become better at troubleshooting. There is always more to learn.
- Perseverance. This is critical to being a good troubleshooter. There are many times when standing at a molding machine for hours gets very tiring. A good troubleshooter is willing to put the time and effort in to ensure the problem is corrected. This also means that they will check back on the problem to ensure that it is corrected.
- Willingness to try things. If a troubleshooter is afraid to try something out of fear of a negative result they will struggle to reach the solution of the problem. A perfect example is a processor who is afraid to open up vents on a mold because of flash. If you do not try to fix the problem it will not be resolved.
- Taking a systematic approach. A good troubleshooter works through a problem using a systematic methodology. Change one thing at a time in an organized fashion and give the change a chance to stabilize.
- Being data driven. Good troubleshooters utilize data to make decisions, and do not rely on assumptions or opinions. If a change is made the data should provide feedback on the whether or not there was an improvement.
- Patience. This may be one of the hardest parts of troubleshooting. Often times a change is made but the troubleshooter is not patient enough to determine the effect and immediately makes another change. Allow processes to stabilize during troubleshooting to determine the ultimate impact.

1.3 What Makes an Ineffective Troubleshooter?

Many of the above characteristics help people to become effective troubleshooters. There are also many traits that make people struggle when troubleshooting including:

- The “know it all”. People that believe they know everything about every aspect of injection molding will one day be in for a rude awakening. Injection molding problems tend to have a humbling effect on troubleshooters, and everyone has something more to learn. Remember every mold, machine, and material combination can create a new opportunity.
- The “this worked last time” syndrome. Many times people get caught in an approach that completely relies on what they have experienced, which in turn puts blinders on them. First understand the problem before trying to implement what worked last time.
- The “Band-Aids and duct tape fixes everything” troubleshooter. This type of person will always look for the simplest thing that can be done whether or not they solve the problem. This mentality often happens in production where the approach can be just “get me the parts I need to make shipment.” While a “duct tape” type of fix may help to limp through a run, the root cause must be addressed and corrected. Putting “Band-Aids” on top of duct tape to keep a job running will lead to scrap and downtime.
- The “flavor of the month”. This often happens when a specific problem is identified and corrected on a given mold in the plant. Often since this solution solved that problem people will try to implement that solution everywhere whether it fits or not.

Overall many people that struggle to effectively troubleshoot are lacking either the time or the tools to be successful. There is always only going to be 24 hours in every day and customer demand for quality parts will persist. This book was written to help provide some tools that can make troubleshooting more efficient and hopefully help people wisely use their time spent troubleshooting.

1.4 Troubleshooting Methodology

As mentioned in Section 1.2, a good troubleshooter uses a systematic approach. The following is a reminder to help with keeping a systematic approach to troubleshooting;

Systematically

Think

Observe

Proceed

This STOP methodology of troubleshooting is meant to do exactly what it says and stop before jumping to conclusions.

Development of STOP

This thought process came years ago while interviewing process engineers and technicians. I would always try to gauge their knowledge by asking questions about how they would handle a problem such as a short shot. The answers I received were usually correct to a point but obviously quite diverse. Often times the answers provided could be the right ones, but, without knowing what was happening, could also lead to disaster. When I reviewed my own mentality, I came to understand that the first thing I would do when troubleshooting was to stop and really examine what was happening. The concept of STOP troubleshooting came about as an easy way to train people in the methodology of troubleshooting.

1.4.1 STOP: Systematically

In the STOP methodology, the S stands for systematically. All troubleshooting should be conducted in an organized and systematic approach. Having a systematic approach will help ensure the root cause of the problem is truly resolved. As a problem is addressed a systematic approach will make it easier to avoid missing a potential cause.

Part of the systematic approach to troubleshooting breaks the problem into four key categories. Many people are familiar with the 5M's often used for fishbone diagrams which are man, method, machine, measurement, and material. For systematic injection molding troubleshooting the 4M's we focus on are:

1. Molding process
2. Mold
3. Machine
4. Material

These 4M's are the key items that a troubleshooter can impact. The "man" is not included because a person can impact any of the 4M's. Each of the 4M's must be considered for potential root causes when troubleshooting. By reviewing the 4M's it is much easier to troubleshoot with a systematic approach. By considering which of the 4M's could contribute and working through one category at a time a list of potential root causes can quickly be gathered.

All of the defects discussed in this book will use the 4M method for description of potential causes. Utilize the possible causes to systematically work through resolving the problem. Keep asking which of the 4M's could be contributing to the defect and why. Always try to drive deeper to get to the root cause of the problem. An example of using the 4M's is when troubleshooting sink: the natural place to start is with second-stage pressure; however, if the pressure is raised to compensate for a machine problem, was the true issue resolved or are you processing around another issue? The goal of the 4M method is to avoid processing around issues. Often times molders are left trying to work "process magic" to get good parts when a tooling improvement should have been implemented. Using the 4M method helps to keep process windows as wide as possible and will lead to less scrap, waste, and PPM (defective parts per million) in the long run.

Most people are familiar with the "5 Why" approach that was developed at Toyota. This approach is a tool that systematically drives toward asking questions about the root cause. In this approach, the goal is to get to the true root cause by asking why after every answer when problem solving. Many people find this technique useful.

One key to a systematic approach to troubleshooting is to review what has possibly changed in the mold, molding process, material, or machine. Frequently people will work on trying to fix a problem but not address what had actually changed that originally led to the problem. In other words, sometimes technicians are struggling to solve the wrong problem. A common example of this is someone slowing first-stage velocity to fix a burn that was actually caused by dirty mold vents. Using a systematic approach will help to focus on the true root cause of the problem and not to process around an issue.

The mentality to keep when troubleshooting should be to try to remove one potential root cause at a time. Until an issue has been proven to have no effect it remains a potential root cause. Using a systematic approach allows a troubleshooter to remove one cause at a time, focusing initially on the most likely causes and working from there. Always remember though that data is key to proving a root cause.

Change one thing at a time and determine the impact. If a troubleshooter changes multiple things at a time it is impossible to determine what the root cause was. After making a change, always give the molding machine time to stabilize before evaluating the impact of the change. If the process change shows no impact on the defect, it can be reset to the original documented process.

It is also vital to make changes that are large enough to have a potential impact. Frequently processors will make an adjustment to a process and when they do not see an impact they scratch that variable off the list of potential causes. Remember that if the change is too large and causes other concerns it can be adjusted back towards the original setting. Make sure a parameter has been thoroughly evaluated before it is removed as a potential root cause.

1.4.2 STOP: Think

Think is the step to make sure that a troubleshooter has mentally reviewed the defect and the potential causes that were systematically determined. Before making a change, it is critical to think through what the expected result is as well as potential side effects. Always begin the think step with the question of “is this a new problem or has it been ongoing?” If it is a new problem focus on what changed; with an ongoing problem the focus is more on what needs to be corrected.

Sometimes in the think step of troubleshooting it is necessary to think outside of the box. Many problems encountered in molding are not easily solved and may require a creative approach to resolve. Willingness to not be constrained by comments such as “that’s not the way we do it” is key to resolving problems. As Albert Einstein said, “we cannot solve our problems with the same thinking we used when we created them.” There are many examples of molds where someone said that an area cannot be vented or cooled but through some ingenuity a solution was found. Remember that there are many exceptions to the general “rules of thumb”; critical thinking is vital.

Also, when thinking through a problem, think bigger than the current defect that is in front of you. Always ask if this problem may be happening elsewhere but has not been detected there. In the case of the 4M machine category, any mold that runs in that particular machine may be having problems but some will be worse than others. If one drying hopper is feeding multiple machines a splay problem may start to show up in multiple parts. Think about the root cause and what else it may impact and examine other parts that could be experiencing similar problems.

When thinking about a problem look for opportunities to push the thought process as far up front as possible. Effort put into part and mold design will result in improved process windows, reduced scrap, and more efficient launches. It is much more cost effective to ensure that the initial design is suitable for manufacturing rather than trying to correct mistakes after the mold has been built and run.

1.4.3 STOP: Observe

Observation is critical to solving problems. Much like Sherlock Holmes, a good molding troubleshooter must observe as much as they can regarding the problem and environment.

Observation should be a multiple sense process, meaning look, listen, and even smell what is happening at the molding machine. Visual examination of the parts, the equipment, and the process will most often provide valuable clues. However, when observing a molding machine in operation, the smell of degraded plastic may be an overwhelming indicator of a problem. Strange noises can also be an indication of something wrong in the process. Always observe with all senses to try to discover any clues to the cause.

When observing a molding process, a walk around the machine is usually a good practice. A quick walk can often highlight a concern that must be addressed. Key things to look for include:

- Auxiliary setpoints and actual values
  - Hot runner controllers
  - Thermolator
  - Chiller
  - Dryer
  - Gas assist equipment
- Clamp and robot movements
- Trimming operations
- Operator handling
- Material identified and correct
- Clear standards available?
- Anything that is damaged or out of place

Figure 1.1 shows a simple chart called the 4M Basic 8. These are the basic items that need to be observed during initial troubleshooting. Many problems can be resolved by simply working through these eight questions, and a “no” answer for any of these questions indicates a likely starting point for resolving the problem. The 4M Basic 8 is a very simple procedure that all molders should be able to work through and answer prior to calling for technical support. Utilizing the 4M Basic 8 or something similar as a starting point for troubleshooting puts good habits in place for troubleshooters.

	4M Basic 8	Y/N
	Molding Process	■
1	Match documented setup?	
2	Fill Only Weight?	
	Mold	■
3	Vents clean and open?	
4	Mold not damaged?	
	Machine	■
5	Same machine?	
6	Machine achieving setpoints?	
	Material	■
7	Correct material?	
8	Dry?	

Figure 1.1 4M Basic 8

Another key to the observation step of the STOP methodology is to ensure that good baseline data is available. Scrap reports are a critical piece of data to determine what the baseline defect rate is. Figure 1.2 shows a pie chart that provides a breakdown of the key scrap items for a particular job. Based on the Pareto Principle a likely expectation is that 80% of the scrap is a result of 20% of the potential root causes. This pie chart provides an easy reference tool to determine where the troubleshooting efforts should be focused.

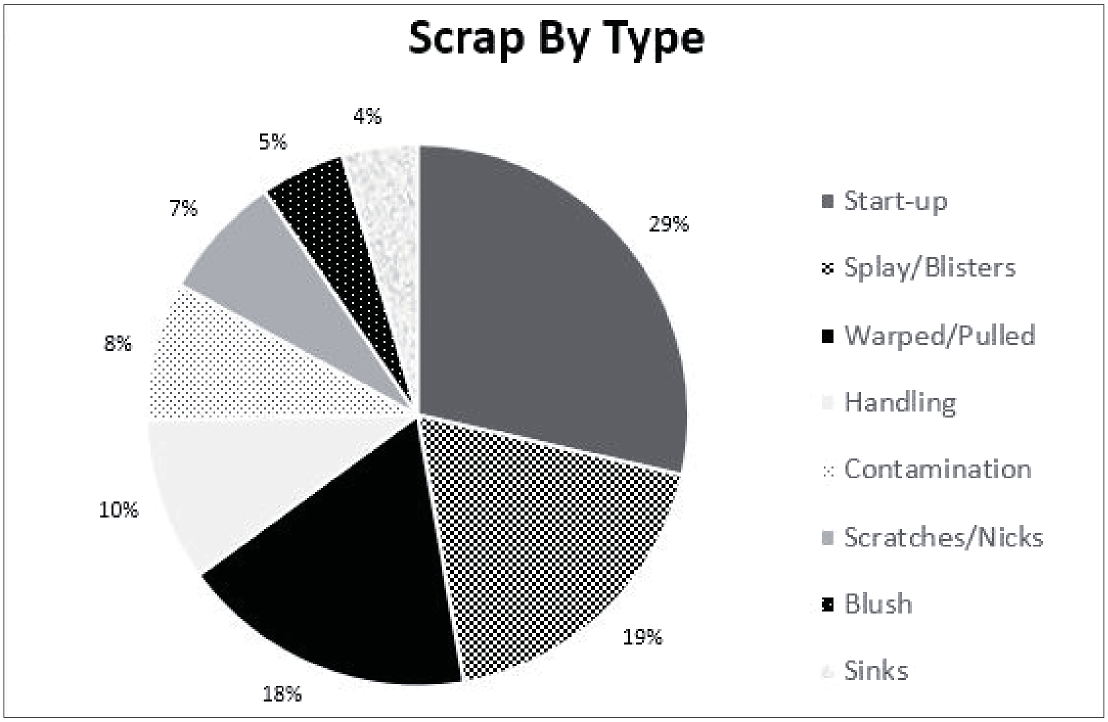


Figure 1.2 Pie chart breakdown of scrap percentage

A key observation task when reviewing data during troubleshooting is to evaluate if the problem has been an ongoing issue or has just recently started to occur. Figure 1.3 shows a graph that greatly illustrates an example of a sudden appearance of a defect. The part had been running with very little contamination scrap (less than 10% of total scrap) but then in June the contamination scrap numbers started to rapidly increase. The job continued to run poorly for approximately 5 months until the root cause was determined (problem with agglomeration of colorant components in the color concentrate). Validation of the improvement was simple due to the rapid drop of scrap in November.

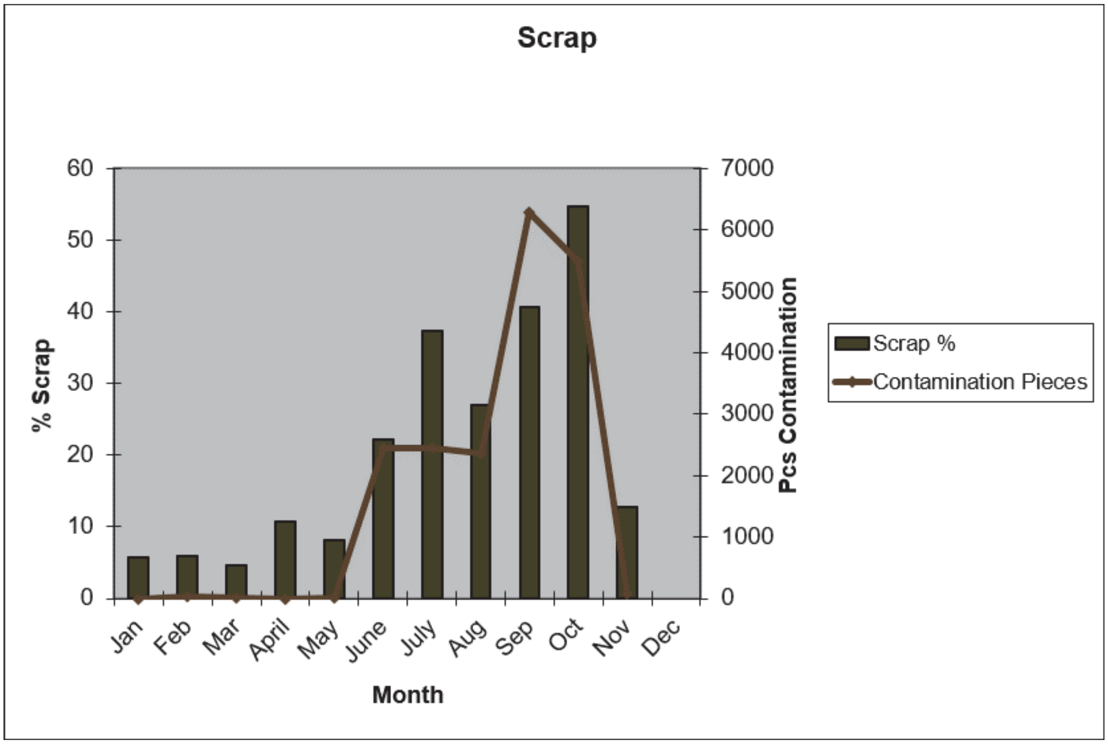


Figure 1.3 Graph showing a sudden increase in scrap and a corresponding sudden drop off in scrap after the problem was fixed

If a problem suddenly occurs the most important question to answer is "what has changed?" The power of observation is critical to determining what potentially changed. The 4M Basic 8 helps to evaluate possible changes and this simple step should always be done before diving deeper into the problem-solving process. It is important to understand that a sudden change may not have been something that someone did intentionally. Things that must be observed for possible unintentional change include:

- Shop environment
- Material variation

- Machine wear or damage
- Mold wear or damage

Any change in the above factors may lead to a condition that exceeds the ability of the molding process for producing quality parts.

When observation of the baseline data shows that the problem has always existed, the main question is not “what changed?” but rather “what must be changed?” There are many parts in manufacturing operations that have such small process windows that they produce a steady stream of scrap. If the part has been steadily producing scrap it is often more difficult to troubleshoot because the problem may be rooted in several factors and not in a simple change. If observation shows that the part has had defects since it was launched, all of the 4M’s must be reviewed in depth for possible causes. A common situation found in troubleshooting is where a process was established to work around another issue such as venting in a mold. Rather than finding and correcting the root cause during process development, the processor worked his/her magic and developed a process that produced “good” parts. Sometimes it is only after the mold has had some run time in manufacturing that the true ramifications of the narrowed process window are understood.

In many cases a troubleshooter will find that ongoing scrap problems are rooted in processing around a mold, machine, or material concern. It cannot be stated enough that molders must not process around problems but rather need to have the problems fixed to maximize process windows and minimize scrap and cost. Putting “Band-Aids” on a problem will not help establish a robust process; fix the problem! To effectively resolve problems the technical groups must work together. If the maintenance or tooling department will not fix the problems that are encountered the processor is left holding the bag and will have to process around a root cause.

1.4.4 STOP: Proceed

This is the step that everyone is anxious to get to because this is where actual changes are tried. The problem that frequently occurs is that people will jump to trying things without going through the systematic, thinking, and observing phases of troubleshooting.

Jumping right into making changes can lead to damage to equipment or molds. Figure 1.4 illustrates an example from someone who jumped to a solution. In this case, the machine was producing short shots and losing cushion, so the technician increased the shot size to add more plastic to the cavity during first-stage inject. The problem here was not a shot size issue but rather where the plastic was going. As the photo shows the hot runner manifold was leaking and was encapsulated in plastic while running. This hot runner manifold had to be torn apart and cleaned, have the leak repaired, and be rewired with new heaters and thermocouples.

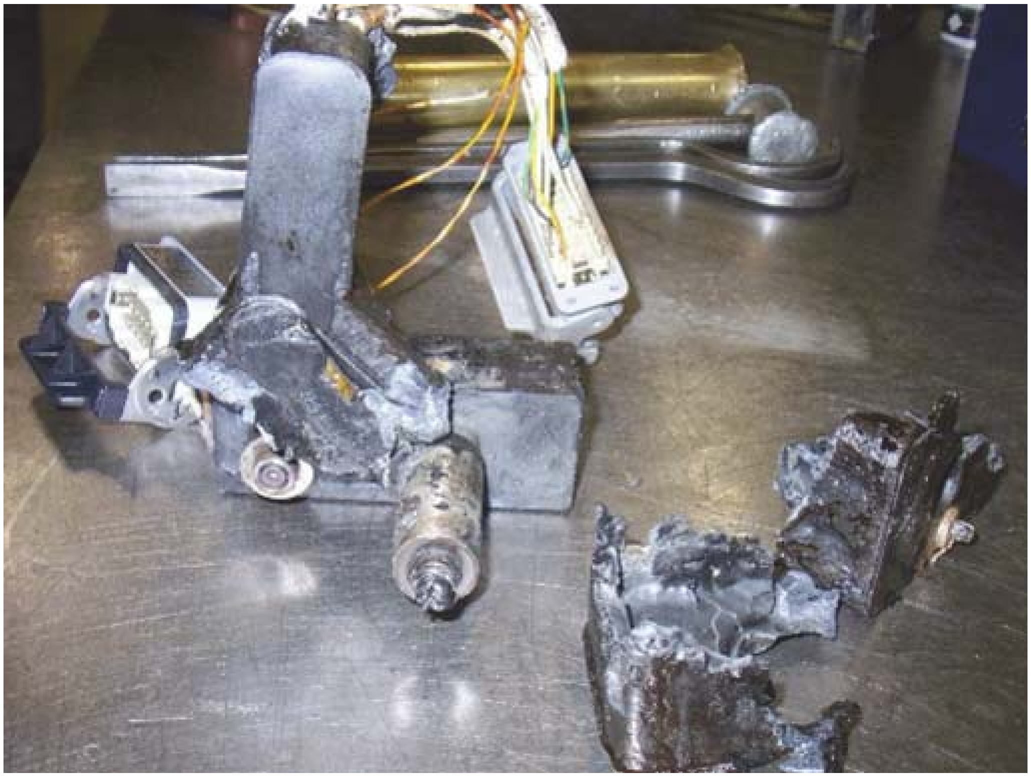


Figure 1.4 Effect of jumping to action without understanding the problem: a hot runner manifold encased in plastic

When the systematic, think, and observe steps have been completed and a direction is determined, it is time to make the change and evaluate the impact. Keep in mind that when the problem gets worse, that is indicating that the setpoint may have been adjusted the wrong way. Change is key when observing the impact of an adjustment: if there is no change the parameter is not the root cause.

When an adjustment is made that seems to improve the defect evaluate the following:

- Is the process adjustment within the allowed process window?
- Is the part cosmetically acceptable?
- Is the part dimensionally acceptable?
- Does the part meet all testing requirements?
- Does the part meet all other requirements?

If an adjustment successfully solves a problem make sure to dig a step deeper:

- Why was this adjustment required?
- What impact did the adjustment have on the plastic conditions in the cavity?

- Is the new condition stable and capable of producing quality parts for the long term?
- Is there anything else that should be done to ensure an adequate process window?
- Could this problem be affecting other product being produced?
- Does something in the company systems need to be changed to prevent this problem from reoccurring?

During the proceed step of STOP troubleshooting it is important to remember to review the results. If a process technician or engineer makes a change and does not examine the results they will have no way of evaluating if the change made a difference. There have been plenty of cases where a change was made and everything seemed good only for it later to be found that the data showed no difference. Always compare the results from after the change with the baseline data to determine if the change truly made a difference.

Some problem jobs may have a proceed step that lasts for an extended period of time to monitor the results to ensure that the problem has been eliminated. When all is said and done the data will tell the story.

1.4.5 STOP: Troubleshooting Cycle

It is critical to understand that the STOP methodology should be used as a cycle. After proceeding to make change it is time to go back to Systematic, Think, and Observe to work through evaluating if the change had the desired impact and if not, why? See Figure 1.5 for an illustration of the STOP troubleshooting cycle.

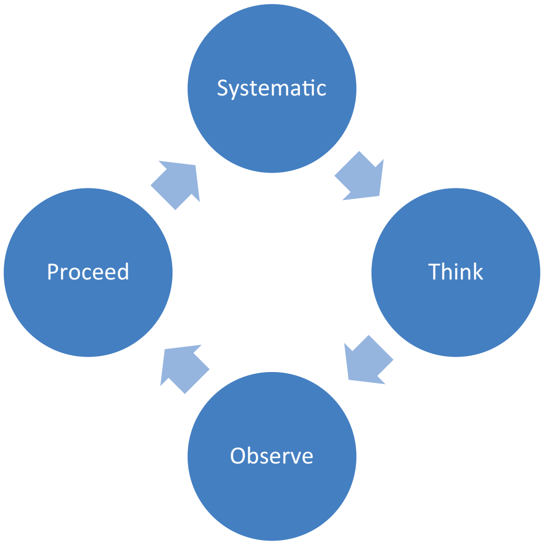


Figure 1.5 STOP Troubleshooting cycle

Continue to work through the STOP methodology cycle until the root cause is determined, corrected, and verified. Remember that it may take weeks of run time to fully determine the true impact of the change.

1.4.6 Hard Fix versus Processing around Problem

Whenever possible a permanent hard fix should be implemented to resolve the true root cause of the issue. If a physical change can be implemented in the mold or part design, the process window tends to be much larger. Implementing a hard fix to a mold may involve some up-front cost but will lead to long-term savings. Do not be short-sighted when troubleshooting, but rather think of the multiple years that the mold may run in production.

The importance of implementing a hard fix becomes more magnified when considered against the human ability to detect part defects. If the plant quality system is relying on detection from a person to catch defects the resulting customer returns will become very costly. However, if a hard fix is implemented the defects are prevented and human error and judgment do not play into shipping bad parts to the customer. Do not rely on human detection; prevention is the key to eliminating shipping bad product.

1.4.7 Troubleshooting Tools

In addition to the 4M methodology discussed above there are many additional tools and techniques that can help with troubleshooting including the following:

- 5 Why
- Fishbone diagram
- Scrap recording sheets
- Brainstorming
- Design of experiments (DOE)
- Is/Is Not
- Change log

1.4.7.1 5 Why

5 Why is a process that was developed by Sakichi Toyoda and used initially at Toyota for problem solving. The intent of the 5 Why process is to continue to ask questions until the true root cause is determined. An example would be:

- Problem with splay on parts.
  - Why? Material is wet.

- Why? Lack of drying time.
- Why? Hopper was not loaded in time.
- Why? Machine did not have an auto loader and had to rely on a material handler to load the dryer.
- Why? A decision was made to not spend the money to purchase the auto loader.

Using the 5 Why process helps drive down to the ultimate root cause by continuing to dig for the root cause. There will be times when the root cause is determined before 5 Whys have been asked and in some cases, it may even be required for additional questions to be asked.

1.4.7.2 Fishbone Diagram

The fishbone or Ishikawa diagram was developed by Kaoru Ishikawa in the 1960s. The diagram is frequently called a fishbone because of the fish-like shape that the diagram is drawn as. A fishbone typically looks at man, method, machine, measurement, and materials as categories of potential root causes. Each of the five categories is placed on the top line of the fishbone diagram and then additional bones (lines) are added below it to detail potential root causes.

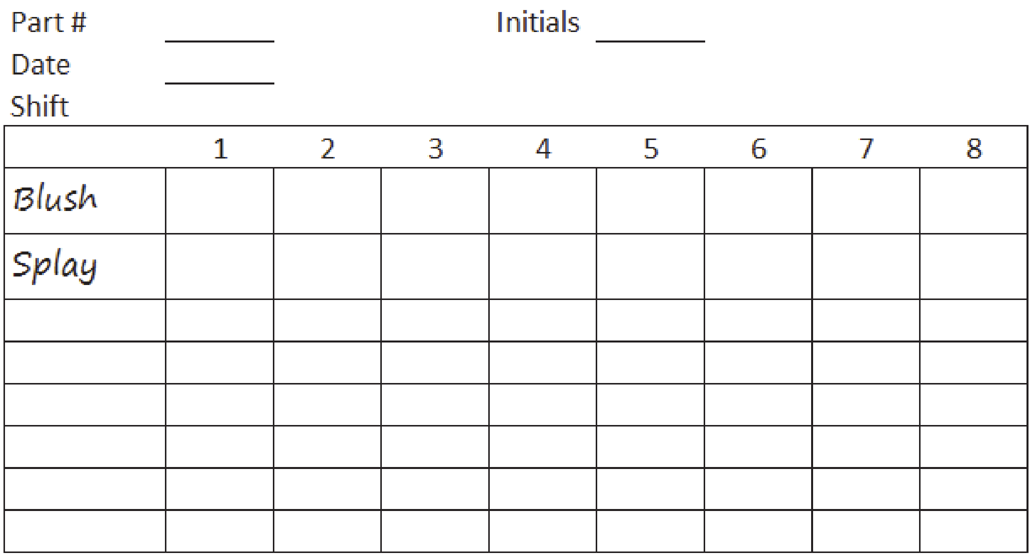
As the 4M troubleshooting methodology was developed it became clear that the key categories molders need to worry about are molding process, mold, machine, and material. As mentioned previously the additional M of the man/woman can impact any of the 4M's.

1.4.7.3 Scrap Recording Sheets

One of the keys to effective troubleshooting is to have good data. There are many types of sheets that can be put together to capture the required scrap data. At the basic level, having a Pareto chart of the various defects is critical.

Another useful tool may be a tally sheet that documents scrap by the hour throughout the day. This can help to determine if a defect if it occurs at specific times or more during specific shifts. Sometimes these tally sheets may show that at the start of each shift the scrap increases until the operator gets up to pace. See Figure 1.6 for an example of a scrap tally sheet; notice there is a box for each hour of the shift for specific defects.

An additional scrap tracking sheet that can be useful is a printed-out example of the part. The operator than simply makes a mark where the defect occurred on the part. Using this type of tally sheet will help establish if a defect is in a consistent location or scattered throughout the part. In some cases, leaving a part at the machine to mark the defect locations can also work.



Part # ________ Initials ________
Date ________
Shift

	1	2	3	4	5	6	7	8
Blush								
Splay								

Figure 1.6 Scrap tally sheet

1.4.7.4 Brainstorming

Brainstorming can be conducted in a variety of fashions but is basically intended to gather some people together to capture as many potential causes as possible. The normal intent of brainstorming is that people can feed off of the ideas of others to build on concepts. Brainstorming can be an effective way of establishing potential root causes.

Some of the common brainstorming techniques include:

- Wide open. In wide-open brainstorming everyone can call out ideas as they come to them. The advantage of this method is that people may build on another's ideas. The disadvantages of this method are that quiet people might not speak up, and the free-flowing dialogue may disrupt creative thinking (or help it depending on the person).
- Round robin. In the round-robin approach a facilitator asks people around the room for an idea and then documents the idea. Advantages of this method are that quiet people get a chance to contribute and it is more focused than the wide-open method. A disadvantage is that there may be not as much of a group dynamic.
- Silent start. In this method everyone starts out the session by writing down a list of ideas. After a set period of time the facilitator asks for ideas and then documents them. Advantages of this method are that it limits group-think concerns and may allow more focused thinking. Disadvantages can include less initial discussion and leapfrogging from others' ideas.

Another thing to think about is adding both subject area “experts” as well as outsiders. Often times the outsiders will ask questions that can spark non-traditional thinking which in turn may lead to the true solution.

Alex Osborn is known as the originator of brainstorming and the basic rules he established are:

1. Do not criticize.
2. Wild ideas are welcome.
3. Go for quantity.
4. Build on others’ ideas.

1.4.7.5 Design of Experiments (DOE)

DOE is a tool that creates an intentional set of experimental conditions that will help determine the impact of problems. The power of DOE is that it combines conditions in a way so as to limit the total number of experiments conducted during a trial. By utilizing DOE it is possible to capture interactions between process conditions and see what the major contributing factors are. There are numerous software packages on the market that can help develop DOE and analyze the data. Specifics on DOE are beyond the scope of this book, but it should be considered as a troubleshooting tool.

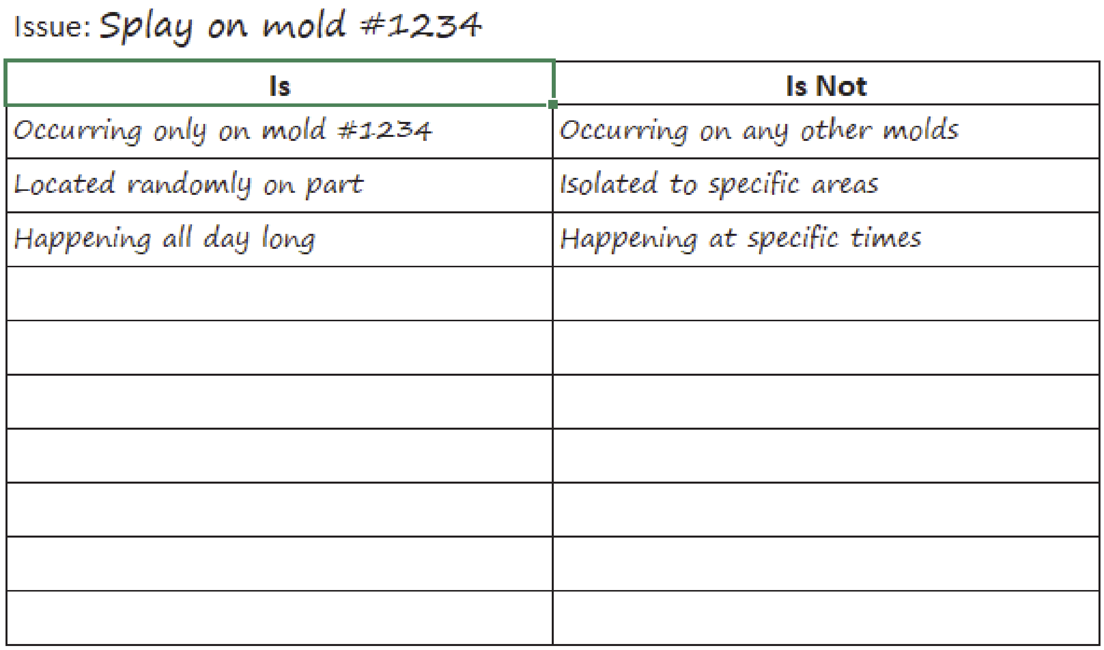
Sometimes simple full factorial DOE is the ticket to finding a solution. In a full factorial DOE there is no simplification of the number of experiments to be run. An example of a full factorial DOE may be looking at the influence of mold temperature and second-stage pressure on part dimensions. A full factorial DOE in this case would require the following runs:

1. Cold mold, low second-stage pressure
2. Warm mold, low second-stage pressure
3. Cold mold, high second-stage pressure
4. Warm mold, high second-stage pressure

These four experiments will determine the impact of these two factors. Adding a third factor would increase the number of experiments resulting in more time required to conduct the trials.

1.4.7.6 Is/Is Not

Is/is not can be applied as a simple tool to help narrow the scope of a problem. The way to conduct an is/is not evaluation is to make a chart with headings of “is” and “is not”. The problem is then broken down into statements about what it is or is not, as shown in Figure 1.7.



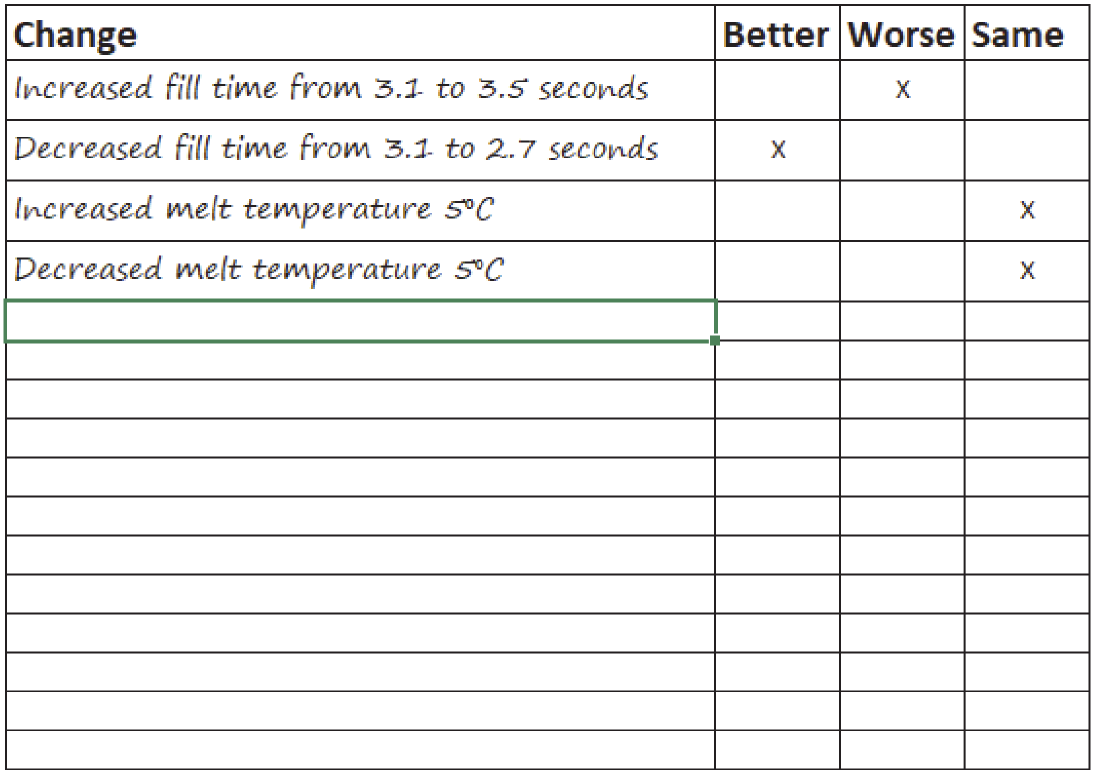
Issue: Splay on mold #1234

Is	Is Not
Occurring only on mold #1234	Occurring on any other molds
Located randomly on part	Isolated to specific areas
Happening all day long	Happening at specific times

Figure 1.7 Is/Is Not example

1.4.7.7 Change Log

A change log can be used to help keep troubleshooting systematic by providing a way to track the changes made. A change log can be something such as Figure 1.8, which provides a simple sheet to record any changes and the impact that they had on the defect. This can be handy for communicating across shifts so everyone can see what was adjusted and the impact the change had on the problem.



Change	Better	Worse	Same
Increased fill time from 3.1 to 3.5 seconds		x	
Decreased fill time from 3.1 to 2.7 seconds	x		
Increased melt temperature 5°C			x
Decreased melt temperature 5°C			x

Figure 1.8 Example of a change log

1.4.8 Troubleshooting Methodology Summary

There are many useful tools that can be applied to troubleshooting. This chapter detailed many of these tools but especially focused on the STOP methodology of troubleshooting and the 4M method.

STOP troubleshooting focuses on:

- Systematic
- Think
- Observe
- Proceed

The 4M method is how all of the defects in this book are discussed. All defects are considered based on:

- Molding process
- Mold
- Machine
- Material

Be sure to ask whether the problem is a new issue or has been ongoing. This can help focus the troubleshooting because new problems need to be approached by looking for what changed.

Troubleshooting is a skill that can be built with knowledge and experience. Be willing to ask questions and dig for answers. Change one thing at a time and allow the process to stabilize.

Make sure that any changes are evaluated for unintended consequences. Be careful not to trade one problem or defect for another. If an adjustment helps reduce scrap but causes assembly problems, the end result may cost more in the long run.

2 Troubleshooting Tool Kit

There are many useful tools that should be available for troubleshooting in a molding operation. Without having critical troubleshooting tools, it will be nearly impossible to effectively troubleshoot a molding problem. Some tools are costly and a plant may have only one available but basic items should be accessible to everyone.

2.1 Lockout/Tagout

Whenever doing anything that involves working between the mold halves, it is critical to ensure proper lockout/tagout of the equipment.

2.2 Hand Tools

A variety of basic hand tools should be on hand when troubleshooting. These tools may include:

- Wrenches, including Allen, adjustable, and box end
- Screwdrivers
- Brass rods, scrapers, and brushes
- Bronze or brass pliers
- Slide hammer
- Various other tools as needed

2.3 Pyrometer

The melt temperature cannot be judged by reading barrel temperatures nor can it be judged by reading a thermolator. For determining actual temperatures, a pyrometer with a fast-acting melt probe and a contact probe must be available. Actual temperature readings are critical when troubleshooting!

2.4 Spotting Blue

To check the surface contact of mold surfaces spotting blue is used. It should be brushed on one surface of the tooling and then the mold is closed and opened and then inspected for transfer of blue onto the clean surface. This is used to verify shut offs and if vents are open.

2.5 Measurement Tools

It is very handy to have a variety of measurement tools on hand. Calipers and micrometers will help give wall stock measurements. Often times a tape measure is more fitting for examining larger dimensions such as size of mold versus platens, total flow length, etc. A depth micrometer is useful for checking actual vent depth.

2.6 Multimeter

In trained hands, a multimeter can be a useful tool for troubleshooting. Whether verifying volts to temperature for thermocouple or checking continuity on a hot runner cable, there are things that need to be checked with a multimeter.

2.7 Process Monitoring Equipment

Process monitoring equipment like RJG's eDART® can be very useful for diagnosing problems at a deeper level. The biggest advantages to using a process monitoring system to help troubleshoot are as follows:

- Allows collection of large amounts of data including:
  - Machine pressures
  - Cavity pressure
  - Mold temperatures
  - Cooling
  - Fill speed
  - Fill profile
  - Dryer function
  - Weather
- Allows storage of data for easy analysis
- Allows a baseline template to be saved
- Allows capture of intermittent problems; it captures data on every shot

The use of process monitoring equipment can be a tremendous benefit to the troubleshooter. It can provide all the data detail to dive deep into every phase of the process.

2.8 Moisture Analyzer

A moisture analyzer is a useful tool to help determine if the material has been adequately dried. A loss on weight moisture analyzer can give a false high reading, however, because it will measure the total weight loss during heating of the material, which could include volatiles other than water.

2.9 Dew Point Meter

To verify that a dryer is working properly the dew point must be measurable. Some dryers have built in dew point monitors but portable meters can be purchased from industrial supply shops. If material drying is the root cause of the problem, conducting a dew point check on the dryer will determine if the dryer is capable of reaching adequate levels (typically −40 °F).

2.10 Flashlight

A flashlight is a cheap tool that is valuable to help see better detail on a part. An example is EDM marks or lack of polish on a core will be much more apparent when using a flashlight for inspection. When looking into a mold that is in the press, shadows will obstruct a clear view, but often times a simple pen light will solve this problem.

2.11 Microscope/Magnifying Glass

Sometimes magnification is the only way to identify what a defect really is. Having a magnifying glass and/or a portable microscope can allow a much closer examination of the defect to determine for example if it is splay or a scratch. Portable USB microscopes are now available for low cost and allow photographing of a defect or area of concern, which is very useful when communicating a problem.

2.12 Silly Putty

Silly putty is a very simple item that can prove useful. When wondering if a particular defect is in the mold steel, pressing silly putty unto the area can sometimes provide a clear answer. It is also very useful for looking at small and hard-to-see details such as date wheels.

2.13 Inspection Mirror

Inspection mirrors are a handy item to help see hidden areas in a mold, and can as well as be used to inspect other challenging areas such as feed throats.

2.14 Thermal Imaging Camera

Costs of infrared thermal imaging cameras has come down to a level that is much easier to justify. Use of a thermal imaging camera on parts will help provide an accurate view of the “part out temperature” after the part is ejected from the mold. These thermal images can be used to detect hot spots that may indicate cooling issues. Thermal imaging of nozzle and barrel heaters can also indicate hot or cold spots that should be addressed. Thermal imaging is a very useful tool to help with cycle time optimization; in fact, the savings from this alone will justify the capital investment in a camera.

2.15 Aluminum Tape

A quick check to determine if improved venting will solve a problem is to add aluminum tape to the parting line near the area of concern to allow for additional venting. If this improves the issue the venting should be added or deepened.

See also Chapter 7, which covers venting.

2.16 Dial Indicator

A dial indicator on an adjustable arm can be used to check for mold deflection. When troubleshooting flash, it is critical to know if the mold is being blown open with injection pressure. Setting up a dial indicator and watching for movement can usually prove if clamp tonnage is a root cause.

2.17 Purging Compound

When dealing with contamination-type defects, having a purging compound can allow the barrel and machine to be cleaned out of contaminating resin and carbon buildup (at least to a point).

■ 2.18 Grinder/Stones

Access to grinding tools and stones will allow vents to be opened up on a mold suffering from venting related problems. Caution with these items is extremely important so as not to cause damage to the parting line of the mold, which would in turn lead to flash.

■ 2.19 Camera

With cell phone cameras, this is an easy item to have on hand. Using a camera to document defects and impact of changes will allow a clear way to communicate the problem and review any changes.

■ 2.20 Material Data

When troubleshooting it is key to have the material molding recommendations available. This provides an opportunity to cross reference important process values such as melt temperature, mold temperature, drying parameters, venting, and gate recommendations as well as many other process details. Make sure that this data is readily accessible for all troubleshooters.

■ 2.21 Scale

A scale is critical for accurately measuring part weight. Without an accurate scale it is not possible to replicate a fill only shot, which is one of the key checks for a molding process. Also having the ability to measure shot weight will allow analysis of dryer throughput, and approximate barrel residence time.

2.22 Flow Meter

A flow meter is used to measure water flow in a mold. Through the use of a flow meter it is possible to determine if a water line has adequate flow to achieve optimal cooling. Checking the flow across water circuits may show change over time that can indicate problems that can impact the ability of the mold to cool the plastic.

2.23 Mold Cleaning Supplies

A good first step for troubleshooting is to clean the mold using mold cleaner and a wipe. Many defects can be impacted by a dirty mold. Before trying process adjustments, the mold should be cleaned. If the defects go away two things may need to happen:

1. Create a cleaning standard for how and when. Every shift should be cleaning the mold appropriately and this should be occurring on a regular basis. Also standardize cleaning at mold start ups.
2. Evaluate the mold for adequate venting. If the process technicians cannot keep up with cleaning the mold it most likely does not have enough venting.

More effective cleaners such as Zapox may be required to clean significant buildup from a mold surface.

2.24 Miscellaneous Supplies

There are a number of other simple items that make troubleshooting easier including:

- Note pads to help keep track of changes
- Markers to write on sample parts
- Ziplock bags for bagging samples
- A calculator to help with math
- A sealed container for samples for moisture analysis (i.e., glass bottle)

3

Decoupled® or Scientific Molding

Most of the methods discussed in this chapter are those developed and taught by Don Paulson [1], John Bozzelli [2], and Rod Groleau [3]. There is a large amount of excellent information available on Decoupled®/scientific molding, so this chapter will only cover the basics [4].

One of the Merriam-Webster dictionary definitions of scientific is as follows:

Conducted in the manner of science or according to results of investigation by science: practicing or using **thorough or systematic methods***.*

This is the foundation that Decoupled®/scientific molding is built on, thorough and systematic, and is also a great definition for how effective troubleshooting should be conducted.

The basic premise of Decoupled®/scientific molding follows these steps:

1. Fill the mold to 95–98% full using first-stage velocity control. Filling should be as fast as possible while making a quality part. The molding machine must not be pressure limited meaning that the required pressure to achieve desired fill velocity should not reach the machine's maximum pressure (actually anything within 2000 psi plastic pressure should be considered pressure limited; this allows for compensation due to viscosity variation). The 95–98% short shot is referred to as a fill only shot.
2. Conduct a cavity balance study if running a multi cavity mold. See Chapter 12 (Cavity Balance) for more details.
3. Transfer from first-stage velocity control to second-stage pressure control by using the transfer position setting on the machine.
4. Control pressure during second stage to compensate for plastic shrinkage during cooling.
5. Second-stage pressure should be controlled for a set time period. This time period should be determined by conducting a gate seal study [5]. For every mold determine if running with gate seal provides the best quality part.
6. Cooling time will be optimized to minimize cycle time, based on part ejection temperatures.

7. The screw should normally recover to shot size approximately 2–3 seconds prior to mold open. This may require use of a screw rotate delay to avoid rotating the screw at extremely slow speeds.

These basic steps are the process methods that this book will reference. Note that the particular process method is Decoupled II® molding as defined by RJG Inc.

The key is to use a scientific approach and let data help with decision making. Decisions should be made based on data. Use of the STOP method (see Chapter 1) will help reinforce making the effort to gather the data. Also when using this method, focus on recording the plastic data; for example, record fill time and fill only weight rather than worrying about velocity set points. By using plastic data it is possible to translate from machine to machine and process to process.

Modern scientific molding relies on establishing and documenting a process and then always running that process. The days of process technicians having a "little black book" of their personal processes are long gone. If someone has an idea to improve a process it must be approached with data, proper evaluation, and validation. The process technicians should understand that even though they think the process is better all impacts must be examined. There is a saying that the "law of unintended consequences" can create wide-ranging impacts that were never considered. Depending on customer and part requirements it may be necessary to resubmit parts and extensive test data to support a process change.

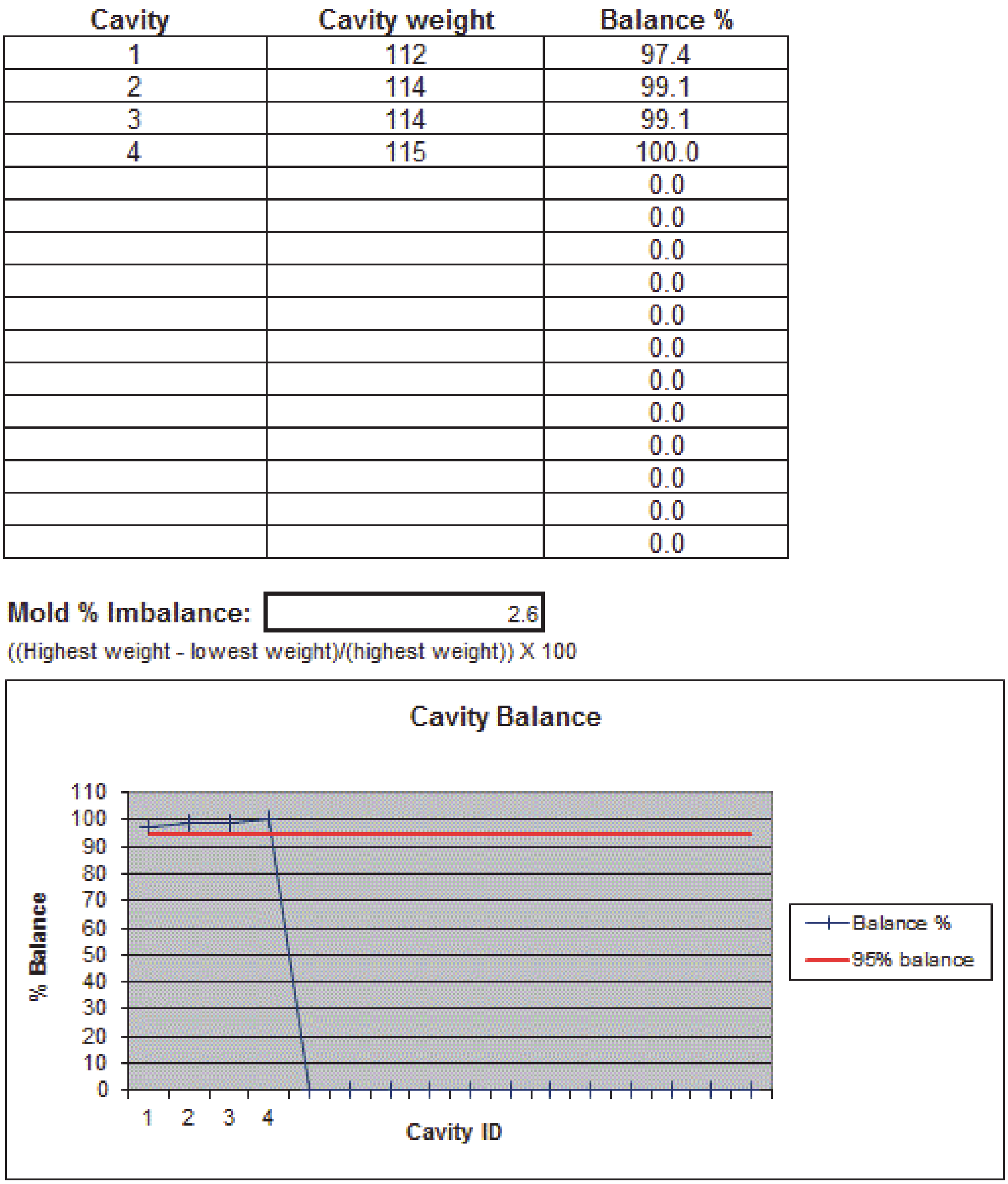
From a practical standpoint everyone in the molding operation must be knowledgeable in scientific molding methods. Once people understand that the process was based on decisions that are backed with data they will tend to take more ownership of the process variables. Quality training in the techniques is absolutely critical to success.

Benefits of Decoupled®/scientific molding include:

1. Faster fill rates yield faster cycle times.
2. Faster fill rates yield lower and more consistent viscosity. Lower viscosity allows easier filling of the mold and less pressure drop across the cavity.
3. Separating first-stage fill from second-stage pack/hold gives the processor the ability to impact plastic flow rates and plastic pressurization as independent points of control.
4. Utilizing a fill only weight of 95–98% will help prevent mold damage and flash from rapid spikes in cavity pressure.
5. Use of gate seal studies ensures that second-stage time is not wasted packing out runners.
6. Cavity balance studies ensure that each cavity is experiencing the same plastic conditions throughout the process.

7. Data generated during process development is always available for later troubleshooting.

Utilize computer-based spreadsheets to create process “setup” forms that capture the data generated during molding process development. With some creativity a spreadsheet can easily be constructed that provides all of the calculations and graphing that is needed to define a process. Selection menus can be created that allow selection of machines or materials that automatically populate specific portions of the spreadsheet, for example intensification ratio and tonnage for a desired machine. See Figure 3.1 below for an example of a cavity balance spreadsheet form.



Cavity	Cavity weight	Balance %
1	112	97.4
2	114	99.1
3	114	99.1
4	115	100.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0
		0.0

Mold % Imbalance: 2.6

((Highest weight - lowest weight)/(highest weight)) X 100

Figure 3.1 Cavity balance spreadsheet

Whenever possible a process should be kept as simple as possible. If first-stage fill does not need to be profiled why use six steps of profiling? Every extra level of complexity in the process leads to more opportunities for a mistake to happen. It is much easier to validate that the fill only weight and fill match the documented process than to try to determine if every step of a complex profile matches what it should. As Albert Einstein put it, "everything should be made as simple as possible, but not simpler."

To be successful with these molding principles it is absolutely critical to not process around material, mold, or machine problems. The 4M method of molding troubleshooting (see Chapter 1) helps to focus on eliminating problems. Instead of blaming the process because fast fill rates lead to burns, it is much better to correct the venting on the mold than use the process method as an excuse. Scientific/Decoupled® molding is very effective but molders cannot expect success if they are trying to process around other issues.

Another key to successful implementation of scientific/Decoupled® molding methods is that all processors in the molding plant must understand the tools used to develop processes and be confident that they work. If a process is developed in a typical Decoupled II® methodology with a fill only weight at 98% full and someone decides to fill the part farther it is likely that the mold will flash. Blaming this flash on the method is foolish; instead the processor must understand the tools that the process is built with. Training is foundational to successful molding, as without adequate training the personnel will feel like the processes are being "tossed over the wall" into manufacturing and may not provide the support required to supply quality parts. Incorporate thorough training for all of the process engineers, technicians, die setters, and material handlers to help eliminate learning from the "school of hard knocks".

References

[1] Paulson Training Programs Inc., 3 Inspiration Lane, Chester CT, 06412; Tel. (860)526-3099; https://www.paulsontraining.com/

[2] Injection Molding Solutions, 1019 Balfour St., Midland MI, 48640; Tel. (989)832-2424; http://www.scientificmolding.com

[3] RJG Inc, 3111 Park Dr., Traverse City MI, 49686; Tel. (231)947-3111; https://rjginc.com/

[4] Groleau, Rod, "The Fundamentals of Decoupled Molding", *Plastics Today*, May 2005

[5] Bozzelli, John, "Why and How to Do Gate Seal Experiments", *Plastics Technology*, Oct 2010

4 Gating Details

4.1 Gating

Gating is a subject that has not had extensive research and most do not understand the impact it has on the process. The gate or hot-drop orifice in most cases is the most restrictive point in the flow of the plastic and so it should be. Gating can impact gate seal time, pressures, cavity imbalance, and defects such as high gates, flaking, jetting, and blush. And when gate modifications are made it is typically an increase in size or gate volume and not the opposite with a decrease in size or volume. But to address some of these issues a reduction in gate size or thickness can be the best approach and varies with the type of plastic you are molding. It is important to understand exactly what the purpose of the gate is, and there is not just one standard or one rule when it comes to gate standards with all the variables involved with part volume, flow lengths, wall stock, and the plastic itself. Always use the STOP process and make sure to think through what contribution the gate has on the process and defects.

Just because you decrease the gate size or thickness, it does not always mean that plastic pressure will increase. And increasing a gate thickness or size does not always mean your plastic pressure will drop. We mention this because it goes against common assumptions.

Most people automatically assume you will have an increase in fill pressures if you go thinner in gate thickness. We have found that it is more about volume, which can be maintained by increasing the width when reducing the gate thickness. Some materials prefer the higher shear with thinner gates. On the other hand, glass-filled materials with higher glass content need runners, hot-drop orifices, and gates as large as possible to reduce pressures and be able to pack out the glass.

Typically, when a gate is made smaller you can expect to see a change in plastic pressure because you have reduced the volume of the gate orifice. But a change in gate size or volume does not always produce a noticeable change in plastic pressure.

It is important not to focus on the gate as the only restriction to plastic flow. The gate land can be a contributor to pressure loss and is often overlooked. There is no advantage to excessive gate land and it can contribute to other issues also. Many people also overlook the role of hot-drop tip orifices. We have often seen people open up gates or runners when the hot-drop tip was the restriction—as would occur, for example, when a hot runner feeds into a cold runner. Remember it is about the area or volume of the hot-drop orifice or gate.

Plastics are understood to flow in what is referred to as fountain flow. Let's assume you have a round runner and experience textbook fountain flow. Then what happens when you take this volume of flow and ram it through a small round orifice into the large space of the cavity? But what if you could change the gate geometry to improve the transition from the runner to the part? Let's use a pressure washer as an example to help paint a mental picture. If you were to put a tip with small round orifice on your pressure washer, what type of stream would you expect to see? Now if you put a tip with a rectangular orifice that was thin and wide, what would the flow look like? The difference is pretty drastic between a small, straight, jetting stream and a fanned-out stream. With the thin-and-wide concept we have been able to reduce cycle times with a quicker gate seal, maintain or reduce fill pressures, eliminate high gates or vestiges on cashew gates, help minimize gate blush, eliminate jetting, eliminate pulls, and eliminate flaking.

Case Study

One example is a PC/ABS part where we were addressing high gate vestige. It had a cashew gate with a 0.040-in diameter orifice. We changed the orifice from 0.040 in round to a rectangular shape of 0.020 × 0.080 in, which increased the gate volume. In this case we were not only able to help reduce the high-gate defect but were able to drop the fill pressures from 16,000 to 11,000 psi. This created a larger process window on a part that had struggled with flash and shorts.

In another example we were able to eliminate two defects—jetting and pulls—on a larger glass-filled PP part that was causing a lot of scrap. The 750-ton tool had no process window allowance to address the defects. The part had two cashew gates with 0.110-in diameter round orifices. In this case we could go thinner but not wider because the geometry of the taper would not allow it. We started by welding up the orifice and going from the 0.110 in round to a 0.050 × 0.110 in rectangle. We were concerned about increasing fill pressures because we were reducing the orifice volume.

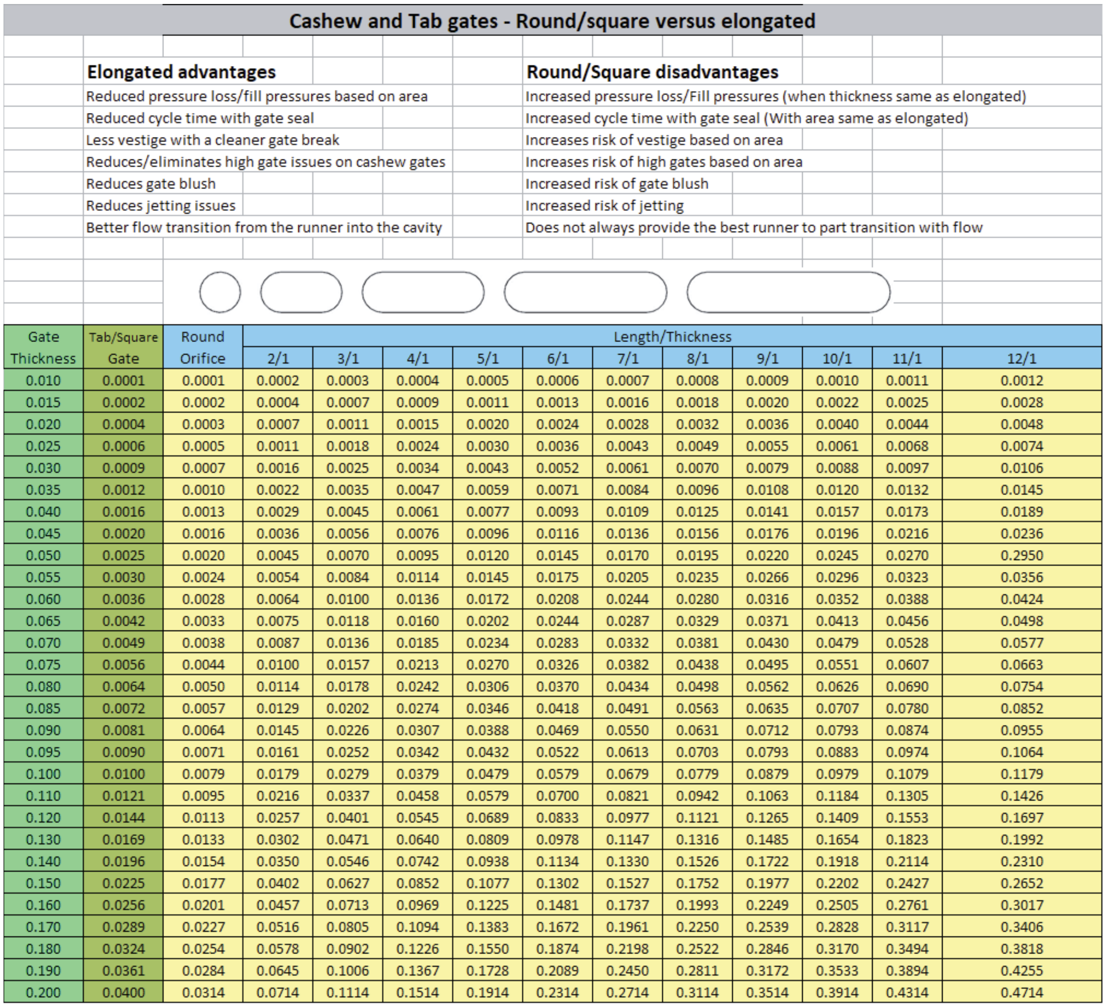
When we ran the tool after the change there was no increase in fill pressures. Jetting was improved but we still had some issues with the pulls. The pulls were the result of the part shrinking away from the gate area before ejection. So, we had another idea: If we made the gate thinner than 0.050 in, would it break while the part was shrinking away, reducing the pull defect? Because the first change had no impact on fill pressures we thought it was worth a shot. We welded the gate orifice and reduced it from 0.050 × 0.110 to 0.025 × 0.110 in.

This time around our fill pressures did increase from around 10,000 psi to 13,000 psi but the pulls were eliminated and the process window drastically improved, with less jetting and thousands of dollars in scrap savings.

We worked on a program of PP parts that were having high-gate issues. In this case the cashew gates had a 0.040-in diameter. We went to 0.020 × 0.080 in, and the high gates were eliminated, and there was no increase in fill pressures.

4.2 Gate Size, Shape, and Taper

Figure 4.1 and Figure 4.2 show geometry alternatives to the industry standards. The D-gate style sub-gate versus the standard sub/tunnel gate simulates the thin/wide concept and will provide much cleaner gate breaks than the standard sub-gate. And with this style in one case we were able to reduce gate-seal time by 5 seconds, saving an equal amount in overall cycle time. With the D-style sub-gate the taper is taken out of the equation for flow restrictions because there is not a gradual taper of mass like the standard sub-gate. You can also sub-gate into angled walls, where when using a standard sub-gate you would end up with a gate vestige. Also, you can gate into shorter walls than with a standard sub-gate. We have gated into cavity walls that were 0.125 in tall. You have endless opportunities with D-gate orifices. You can increase the tip of the cone on the D-gate to create a wider orifice. It is important to understand the volume of the gate orifice. You can use a much thinner gate orifice because you are increasing volume with the extra width.



Cashew and Tab gates - Round/square versus elongated

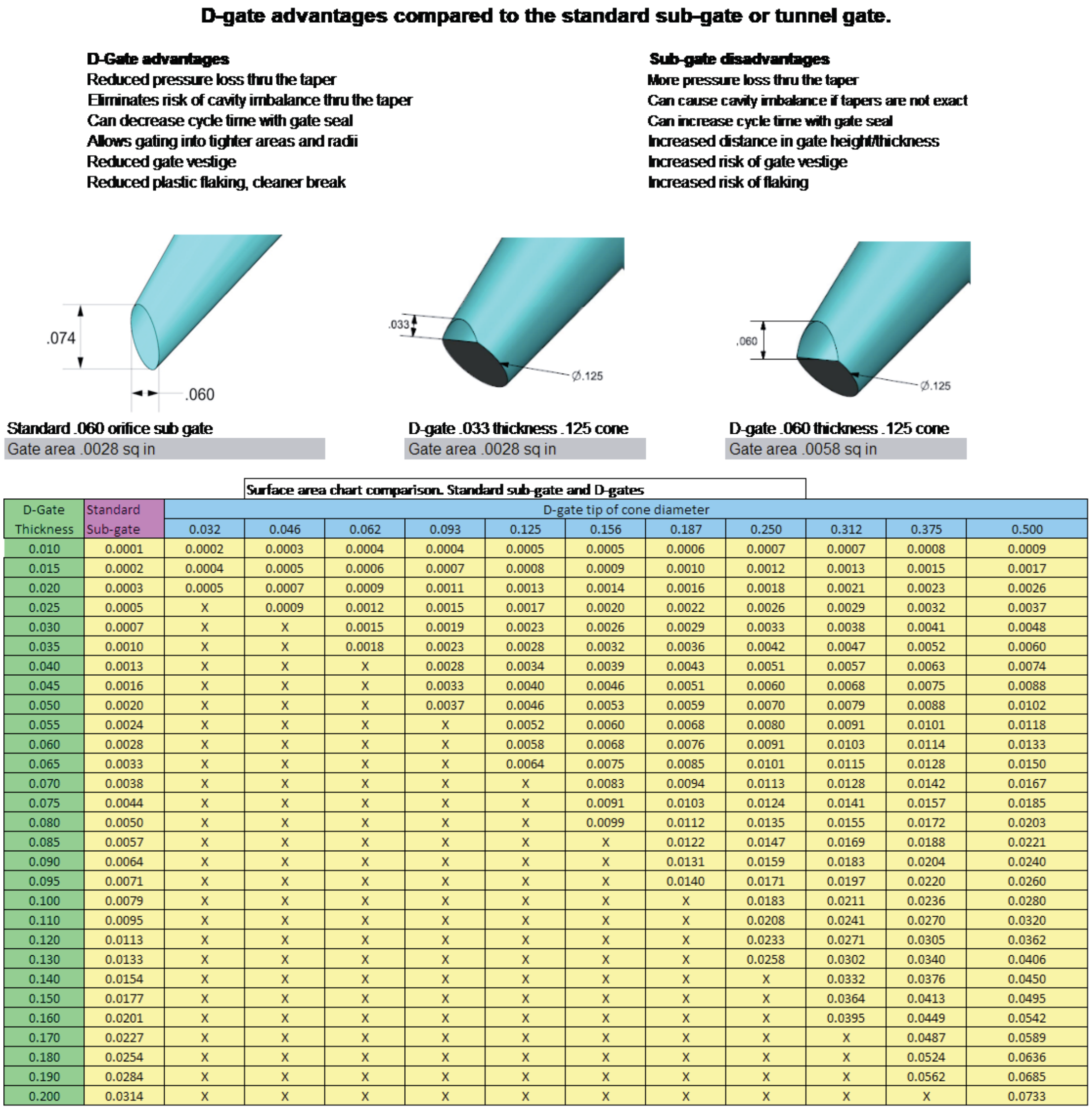
Elongated advantages	**Round/Square disadvantages**
Reduced pressure loss/fill pressures based on area	Increased pressure loss/Fill pressures (when thickness same as elongated)
Reduced cycle time with gate seal	Increased cycle time with gate seal (With area same as elongated)
Less vestige with a cleaner gate break	Increases risk of vestige based on area
Reduces/eliminates high gate issues on cashew gates	Increases risk of high gates based on area
Reduces gate blush	Increased risk of gate blush
Reduces jetting issues	Increased risk of jetting
Better flow transition from the runner into the cavity	Does not always provide the best runner to part transition with flow

Gate Thickness	Tab/Square Gate	Round Orifice	Length/Thickness										
			2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1
0.010	0.0001	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011	0.0012
0.015	0.0002	0.0002	0.0004	0.0007	0.0009	0.0011	0.0013	0.0016	0.0018	0.0020	0.0022	0.0025	0.0028
0.020	0.0004	0.0003	0.0007	0.0011	0.0015	0.0020	0.0024	0.0028	0.0032	0.0036	0.0040	0.0044	0.0048
0.025	0.0006	0.0005	0.0011	0.0018	0.0024	0.0030	0.0036	0.0043	0.0049	0.0055	0.0061	0.0068	0.0074
0.030	0.0009	0.0007	0.0016	0.0025	0.0034	0.0043	0.0052	0.0061	0.0070	0.0079	0.0088	0.0097	0.0106
0.035	0.0012	0.0010	0.0022	0.0035	0.0047	0.0059	0.0071	0.0084	0.0096	0.0108	0.0120	0.0132	0.0145
0.040	0.0016	0.0013	0.0029	0.0045	0.0061	0.0077	0.0093	0.0109	0.0125	0.0141	0.0157	0.0173	0.0189
0.045	0.0020	0.0016	0.0036	0.0056	0.0076	0.0096	0.0116	0.0136	0.0156	0.0176	0.0196	0.0216	0.0236
0.050	0.0025	0.0020	0.0045	0.0070	0.0095	0.0120	0.0145	0.0170	0.0195	0.0220	0.0245	0.0270	0.2950
0.055	0.0030	0.0024	0.0054	0.0084	0.0114	0.0145	0.0175	0.0205	0.0235	0.0266	0.0296	0.0323	0.0356
0.060	0.0036	0.0028	0.0064	0.0100	0.0136	0.0172	0.0208	0.0244	0.0280	0.0316	0.0352	0.0388	0.0424
0.065	0.0042	0.0033	0.0075	0.0118	0.0160	0.0202	0.0244	0.0287	0.0329	0.0371	0.0413	0.0456	0.0498
0.070	0.0049	0.0038	0.0087	0.0136	0.0185	0.0234	0.0283	0.0332	0.0381	0.0430	0.0479	0.0528	0.0577
0.075	0.0056	0.0044	0.0100	0.0157	0.0213	0.0270	0.0326	0.0382	0.0438	0.0495	0.0551	0.0607	0.0663
0.080	0.0064	0.0050	0.0114	0.0178	0.0242	0.0306	0.0370	0.0434	0.0498	0.0562	0.0626	0.0690	0.0754
0.085	0.0072	0.0057	0.0129	0.0202	0.0274	0.0346	0.0418	0.0491	0.0563	0.0635	0.0707	0.0780	0.0852
0.090	0.0081	0.0064	0.0145	0.0226	0.0307	0.0388	0.0469	0.0550	0.0631	0.0712	0.0793	0.0874	0.0955
0.095	0.0090	0.0071	0.0161	0.0252	0.0342	0.0432	0.0522	0.0613	0.0703	0.0793	0.0883	0.0974	0.1064
0.100	0.0100	0.0079	0.0179	0.0279	0.0379	0.0479	0.0579	0.0679	0.0779	0.0879	0.0979	0.1079	0.1179
0.110	0.0121	0.0095	0.0216	0.0337	0.0458	0.0579	0.0700	0.0821	0.0942	0.1063	0.1184	0.1305	0.1426
0.120	0.0144	0.0113	0.0257	0.0401	0.0545	0.0689	0.0833	0.0977	0.1121	0.1265	0.1409	0.1553	0.1697
0.130	0.0169	0.0133	0.0302	0.0471	0.0640	0.0809	0.0978	0.1147	0.1316	0.1485	0.1654	0.1823	0.1992
0.140	0.0196	0.0154	0.0350	0.0546	0.0742	0.0938	0.1134	0.1330	0.1526	0.1722	0.1918	0.2114	0.2310
0.150	0.0225	0.0177	0.0402	0.0627	0.0852	0.1077	0.1302	0.1527	0.1752	0.1977	0.2202	0.2427	0.2652
0.160	0.0256	0.0201	0.0457	0.0713	0.0969	0.1225	0.1481	0.1737	0.1993	0.2249	0.2505	0.2761	0.3017
0.170	0.0289	0.0227	0.0516	0.0805	0.1094	0.1383	0.1672	0.1961	0.2250	0.2539	0.2828	0.3117	0.3406
0.180	0.0324	0.0254	0.0578	0.0902	0.1226	0.1550	0.1874	0.2198	0.2522	0.2846	0.3170	0.3494	0.3818
0.190	0.0361	0.0284	0.0645	0.1006	0.1367	0.1728	0.2089	0.2450	0.2811	0.3172	0.3533	0.3894	0.4255
0.200	0.0400	0.0314	0.0714	0.1114	0.1514	0.1914	0.2314	0.2714	0.3114	0.3514	0.3914	0.4314	0.4714

Figure 4.1 Chart comparing various gate areas

Case Study: Gate Differences

One example of this was on a two-cavity mold with sub-gates. This mold had a right-hand and left-hand part that were exactly mirrored so there was no difference between cavity size but the cavities were significantly unbalanced. I was asked to open up the sub-gate orifice on the cavity that was short even though the gate orifices were the same size (not always a good idea). After opening the orifice to where it had 50% more volume, I knew something was not right. I looked closely and found the sub-gate tapers were slightly different, but not enough to be noticeable without very close examination. I increased the taper on the cavity that was short to match the taper on the other cavity. Wow, what a change! The cavity that had been short now filled way ahead of the other cavity. A D-gate would have eliminated the imbalance because the taper is not gradual to the orifice.



D-gate advantages compared to the standard sub-gate or tunnel gate.

D-Gate advantages	**Sub-gate disadvantages**
Reduced pressure loss thru the taper	More pressure loss thru the taper
Eliminates risk of cavity imbalance thru the taper	Can cause cavity imbalance if tapers are not exact
Can decrease cycle time with gate seal	Can increase cycle time with gate seal
Allows gating into tighter areas and radii	Increased distance in gate height/thickness
Reduced gate vestige	Increased risk of gate vestige
Reduced plastic flaking, cleaner break	Increased risk of flaking

Standard .060 orifice sub gate
Gate area .0028 sq in

D-gate .033 thickness .125 cone
Gate area .0028 sq in

D-gate .060 thickness .125 cone
Gate area .0058 sq in

Surface area chart comparison. Standard sub-gate and D-gates

D-Gate Thickness	Standard Sub-gate	D-gate tip of cone diameter										
		0.032	0.046	0.062	0.093	0.125	0.156	0.187	0.250	0.312	0.375	0.500
0.010	0.0001	0.0002	0.0003	0.0004	0.0004	0.0005	0.0005	0.0006	0.0007	0.0007	0.0008	0.0009
0.015	0.0002	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0012	0.0013	0.0015	0.0017
0.020	0.0003	0.0005	0.0007	0.0009	0.0011	0.0013	0.0014	0.0016	0.0018	0.0021	0.0023	0.0026
0.025	0.0005	X	0.0009	0.0012	0.0015	0.0017	0.0020	0.0022	0.0026	0.0029	0.0032	0.0037
0.030	0.0007	X	X	0.0015	0.0019	0.0023	0.0026	0.0029	0.0033	0.0038	0.0041	0.0048
0.035	0.0010	X	X	0.0018	0.0023	0.0028	0.0032	0.0036	0.0042	0.0047	0.0052	0.0060
0.040	0.0013	X	X	X	0.0028	0.0034	0.0039	0.0043	0.0051	0.0057	0.0063	0.0074
0.045	0.0016	X	X	X	0.0033	0.0040	0.0046	0.0051	0.0060	0.0068	0.0075	0.0088
0.050	0.0020	X	X	X	0.0037	0.0046	0.0053	0.0059	0.0070	0.0079	0.0088	0.0102
0.055	0.0024	X	X	X	X	0.0052	0.0060	0.0068	0.0080	0.0091	0.0101	0.0118
0.060	0.0028	X	X	X	X	0.0058	0.0068	0.0076	0.0091	0.0103	0.0114	0.0133
0.065	0.0033	X	X	X	X	0.0064	0.0075	0.0085	0.0101	0.0115	0.0128	0.0150
0.070	0.0038	X	X	X	X	X	0.0083	0.0094	0.0113	0.0128	0.0142	0.0167
0.075	0.0044	X	X	X	X	X	0.0091	0.0103	0.0124	0.0141	0.0157	0.0185
0.080	0.0050	X	X	X	X	X	0.0099	0.0112	0.0135	0.0155	0.0172	0.0203
0.085	0.0057	X	X	X	X	X	X	0.0122	0.0147	0.0169	0.0188	0.0221
0.090	0.0064	X	X	X	X	X	X	0.0131	0.0159	0.0183	0.0204	0.0240
0.095	0.0071	X	X	X	X	X	X	0.0140	0.0171	0.0197	0.0220	0.0260
0.100	0.0079	X	X	X	X	X	X	X	0.0183	0.0211	0.0236	0.0280
0.110	0.0095	X	X	X	X	X	X	X	0.0208	0.0241	0.0270	0.0320
0.120	0.0113	X	X	X	X	X	X	X	0.0233	0.0271	0.0305	0.0362
0.130	0.0133	X	X	X	X	X	X	X	0.0258	0.0302	0.0340	0.0406
0.140	0.0154	X	X	X	X	X	X	X	X	0.0332	0.0376	0.0450
0.150	0.0177	X	X	X	X	X	X	X	X	0.0364	0.0413	0.0495
0.160	0.0201	X	X	X	X	X	X	X	X	0.0395	0.0449	0.0542
0.170	0.0227	X	X	X	X	X	X	X	X	X	0.0487	0.0589
0.180	0.0254	X	X	X	X	X	X	X	X	X	0.0524	0.0636
0.190	0.0284	X	X	X	X	X	X	X	X	X	0.0562	0.0685
0.200	0.0314	X	X	X	X	X	X	X	X	X	X	0.0733

Figure 4.2 Chart with D-gate area

Case Study: Thin Gate

We had a trailing ring gate on an ABS part with only a 0.006-in gate orifice. On a prototype I had no concerns with fill pressures using a 0.007-in thick gate. When we ran the new tool with a 0.006-in ring gate, our fill pressures were touching the limits on the high side. Needless to say, I was surprised because I had not seen this on the prototype, but the production tool was not an apples-to-apples comparison regarding cavitation or part geometry. We increased the gate thickness to 0.012 in, ran the tool, and the pressures did not drop at all. It was not the gate causing the high pressures.

Now think in reverse: If we had built the tool with a gate that was 0.012-in thick and the process was pressure limited, you would have never considered

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reducing the gate thickness to 0.006 in. You probably would have bet everything you owned that the pressures would have increased. A thickness reduction of 0.006 in may not seem like much, but it was a 50% reduction in gate volume.

Gating and its geometry can have a big impact on shear rates, gate seal, pressures, and quality issues. Most molders and mold makers have their own opinion on gate sizing and many do not keep an open mind on the impact gate size can have on the process and part quality.

To establish gate standards, you have to consider material variation, part wall thickness, and flow lengths. Typically, we would tend to err on the small side, going thin and wide when possible; but with some materials, such as glass-filled nylon, we tend to go much larger, especially with larger parts where there is more volume of plastic to move.

Most of the efforts in the industry to control the injection process involve measuring and controlling injection pressure. This is, of course, a very critical parameter to control and to confirm you have a quality part. But consider the measurement of actual injection volume through the gate, and how it relates to injection pressure, which possibly would be a great tool for process analysis. The gate is typically not a big focus unless there are pressure-loss issues. Pressure-drop studies are the common means to observe the impact of the gate on the process but the industry standard process is flawed and does not take into consideration the impact the gate has.

Case Study: Pressure Drop

A part and process was pressure limited at 24,000 psi, which was the maximum machine pressure available. This was a polypropylene part that had two gates and excessive flow length. The pressure-drop study showed that through the gates we had 9,000 psi pressure drop, and the rest was generated through the cavity. This specific grade of PP had a high viscosity, which contributed to the process being pressure limited. (Running a standard PP required a plastic pressure of only 9,000 psi.)

Some people would have suggested using a higher-pressure machine. I thought I could bring the pressure down slightly with a larger gate size but did not think I would be able to eliminate the pressure-limited issue. The gates were originally 0.020 × 0.080 in and I opened them up to 0.030 × 0.080 in. We then did a pressure-drop study through the new gates, and there was no change: it was still at 9,000 psi, which I found a little surprising. I then opened the gates to 0.040 × 0.080 in and the pressure-drop study still showed 9,000 psi pressure loss through the gates.

Looking back, I see it was not logical to expect this to change much, because we were just shooting a minimal amount of material through the gates, and no matter how big they were we would not see the impact without putting more volume through the gate. We then shot the whole part, and to our amazement the overall pressure drop was now down to 17,000 psi, despite the pressure-drop study still showing the same 9000-psi pressure loss through the gate. Enlarging the gates increased the volume of material that could move through the gate in the same amount of time, allowing the cavity to fill more easily.

Most would assume that the first enlargement of the gates from 0.020 × 0.080 in to 0.030 × 0.080 in was a 50% increase in gate area, and would allow a comparable increase in flow volume per unit time. But you could also argue this was an even greater increase in effective flow orifice. I have no idea of how thick the skinning of plastic around the gate would be, but let's suggest 0.005 in per side. This may be a stretch, but I just want to paint a picture. If we had skinning of 0.005 in per side at the original 0.020-in gate thickness, the remaining flow-channel thickness would be 0.010 in. With the new 0.030-in gate size, the flow channel would be 0.020 in, a 100% increase in effective area and potential flow volume. With this theory, going to 0.040 × 0.080 in gate size would leave a flow-channel thickness of 0.030 in, an increase of 200% over the original size.

You really need to keep an open mind about when you need larger gates and when you need smaller gates. As mentioned earlier, typically reducing gate sizes can eliminate other defects and molded-in stress and in some cases reduce gate seal time.

Many people tend to focus on runner size as much as gate size. Although we agree that the runner should always be a consideration, from our experience 99% of the time the problem is not the runner but the gate or hot-drop orifice. It depends on the length of the runner; if the runner is short, we really do not care if it is round or square, because it has minimal impact on the pressure loss unless it is extremely undersized. Runners in most cases are much larger than they need to be, contributing to excessive waste and in some cases additional cycle time with increasing gate seal times.

Case Study: Hot Drop Restriction

On a part running glass-filled nylon the process was pressure limited at 24,000 psi. Based on the pressure-drop study showing relatively little pressure loss through the runners and gates, it was assumed not much could be done to remedy the situation. This tool had four cavities and a hot runner with two hot drops, each feeding a cold runner and one gate to each cavity. The parts in this case had a long flow length, which also pointed to the

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pressure loss being in the cavity as the study suggested. The process was pressure limited when the part was 50–60% full and was not able to bury all the glass on the part at the end of fill. The gates were 0.080 × 0.125 in and we opened them up to 0.187 × 0.080 in. We saw a very slight improvement but the part was still pressure limited at 80% full.

Our focus then went to the hot-drop orifices, which were at 0.080 in or 2 mm. We opened them up to 0.14 in (3.5 mm) and our pressure drop subsided to 16,500 psi. Again, this approach increased the volume of plastic to the part and ignored what the pressure-drop study was suggesting. This was eye-opening and cast new light on what education in the plastic industry has taught for years, and the lack of attention to the influence of gates or hot-drop orifices. In some cases, it just comes down to reducing the restriction and increasing the volume of material flow, and not always thinking about the psi pressure drop.

4.3 Mental Picture Volume versus Pressure

Let's use a hydraulic cylinder size as an example. A 1.0-in diameter bore in that cylinder has 0.785 in^2 of surface area. A cylinder with a 2-in diameter bore has 3.14 in^2 of surface area in the bore, which is 300% more area. If the hydraulic pressure being used was 1,000 psi, the overall force would also be 300% greater, at 785 lb of force with the 1-in bore vs. 3140 lbf with the 2-in bore. But even though the amount of force is 4 times greater, along with 4 times the volume, the pressure per square inch is still the same at 1,000 psi. If the cylinder bore were instead the gate size or area, the increase in potential volume flow and force into the part would also be 400% and the measurement of injection pressure would show no increase when in actuality the volume flow and process have drastically changed.

Let's use some realistic gate sizes and volume changes. Going from a 0.020 × 0.080 in gate to a 0.040 × 0.080 in gate has at minimum a 100% increase in potential volume flow and force. And going from a 0.050-in diameter to a 0.100-in diameter gate has an increase of at least 250% in potential volume and force.

Again, this consideration of gate area and volume is important mainly when there is an issue with a pressure-limited ability to fill or pack the part adequately. Our current methods using pressure-drop studies focus on one parameter, and assumptions of what is relevant can blind us to the reality of what is happening inside the mold.