SUSTAINABLE IN-MACHINE MOLD CLEANING AND PART DEBURRING & DEFLASHING USING DRY ICE

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Abstract

For plastic processors, there is a great demand to increase the productivity of their equipment and the quality of their parts, while maintaining healthy margins. This can be a balancing act between using the most effective technology while working within a shrinking budget.

This paper discusses the advantages of dry ice cleaning as a replacement for solvent and/or mechanical cleaning for the removal of contaminants from tooling as well as its use to deburr and deflash plastic parts. While the principles discussed herein are applicable to multiple plastics processes (BM, Ext., etc.), the focus of this paper will be on injection molding and the various steel and aluminum mold substrates commonly used.

The reader will achieve a benchmark understanding of the role and relevance of dry ice in mold cleaning, part deburring & deflashing and its impact on product quality, production cost, production efficiencies, worker safety and health and environmental responsibility. Research from several industry case studies will be discussed. The results confirm that dry ice cleaning can remove contaminant layers from various common mold metals and is a good alternative to other commonly used manual, abrasive methods as well as successfully deburr and deflash plastic parts.

Introduction

Mold cleaning remains a critical component of producing quality products. Cleaning mold cavities and vents of resin off-gasses, cured material and mold release agents can prevent a variety of molding problems: burn, sticking parts, short shots, plate-out, contamination, blemishes and flash. But mold cleaning is often delayed because traditional methods cause extended downtime and often involve the use of chemicals or mechanical means harmful to employees and abrasive to the tooling, wearing away critical mold tolerances.

What if you could clean your molds more often, faster, cheaper and non-abrasively, in a sustainable, environmentally responsible manner? What if you could deburr machined plastic parts or deflash molded parts faster and with less labor? Dry ice Environmental Cleaning and Surface Preparation (ECaSP) systems afford molders a proven solution to accomplish these goals and increase productivity, part quality and extend the asset life of the mold.

Dry ice environmental cleaning and surface preparation systems allow for cleaning tools in-line, while they are at operating temperatures, thus increasing machine uptime, mold asset life and profitability. Processors no longer have to remove the tools from the press to spot clean them efficiently and quickly.

Dry ice is proven to clean molds better, while reducing cleaning time up to 75% without causing mold wear. Now molds can be cleaned in a lean, clean and green method, assisting in corporate TPM, 6S, Zero Landfill, 5S and Kaizan initiatives. The August 2012 edition of *TD News* from ToolingDocs included the results of a recent industry poll conducted by the American Mold Builders Association (AMBA), citing that the #2 issue molders deal with is finding ways to improve their “Operational Excellence” (lean manufacturing, waste reduction, zero defects, higher throughput, continuous improvement, scrap reduction, efficiency improvement, etc.). Dry ice cleaning systems can play a significant role in helping molding companies support organizational quality, service and productivity goals, meet industry and evolving governmental regulations and increase profitability.

Such companies that consider maintenance as a critical process of their operations are better able to identify and eliminate costly and time consuming steps from the traditional multi-stage cleaning process to a more efficient one. Yet many molding companies continue to clean by hand using chemicals, solvents and mechanical means (brushes, stones, etc.) that are not only harmful to people and the molds, but also to the environment.

Dry ice or solid carbon dioxide ($C0_2$) cleaning is commonly used in the plastics & rubber industries for a wide range of cleaning applications. There are five (5) takeaways for the plastics and rubber industries noted in this paper: increased quality, increased productivity, extended asset life, reduced operating costs and increased environmental quality.

Definitions

What is dry ice? Dry ice is the generic name for the solid phase of carbon dioxide (CO_2). CO_2 is a gas naturally found in our environment. In fact, it's the same $C0_2$ exhaled by the human body - about 2 lbs of it every day. It is commonly manufactured in four (4) forms, see Fig. 1.

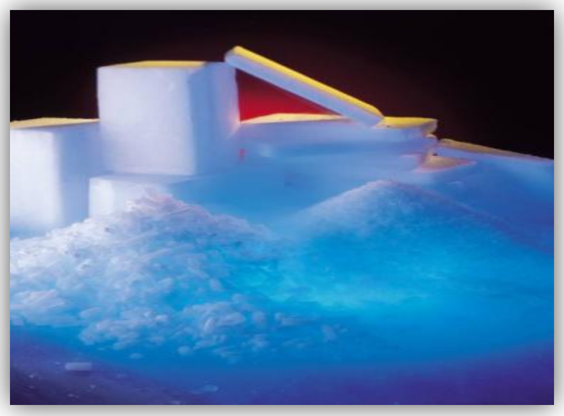


Fig. 1-Typical forms of dry ice from top left to bottom right: block, slice, nugget, pellet.

Dry ice is an abundant by-product of numerous industrial and natural processes, recycled into many useful commercial operations including cleaning and surface preparation. Ninety percent of all CO_2 used to produce dry ice is recycled (or harvested) as a by-product from Ammonia, Natural Gas or Ethanol manufacturing processes.

Which form of dry ice and the subsequent machine selection is determined by the substrate to be cleaned or prepared for a secondary process (i.e. painting). There are machines that can use all forms of dry ice, including scrap dry ice. The equipment utilized and the process will be discussed in greater detail.

Theory and Process

How does the cleaning process work? Dry ice cleaning is known as a non-abrasive, non-toxic cleaning method with unique thermal and sublimation effects [1]. The cleaning process of dry ice cleaning is thought to be based on three criteria: Pellet Kinetic Energy Effect, a Thermal Effect and a Gas Expansion Effect (Spur 1999). The dry cleaning process uses solid CO_2 as a blast media at high velocities.

Pellet Kinetic Energy Effect

The Pellet Kinetic Energy Effect of dry ice cleaning is responsible for most of the cleaning at ambient and typical mold processing temperatures [2]. Therefore, particle speed is an important parameter of dry ice cleaning. Particle speed is mainly (but not linearly) dependent on blasting pressure, but factors such as nozzle type, machine and air supply hose dimensions have an influence. Because the dry ice particles have little hardness, to achieve the optimal Kinetic Energy Effect, dry ice particles are accelerated to supersonic velocity (V) to speeds of 600 feet to 1000 feet/second. Particle speeds are attained by convergence and divergence designs of single and multiple expansion reflection nozzle designs (SERN & MERN).

Another factor in achieving the optimum Kinetic Energy Effect is the particle size: mass, shape and hardness. There are process benefits to selecting the correct particle size for the specific application. Pellets range in size from 3mm to 1mm and tend to be more aggressive because of their greater mass. They are usually better suited for thick or brittle contaminants. Shaved block systems utilize .3mm dry ice particles and while they provide a greater flux density, they provide a less aggressive clean. They are usually best suited for thin, hard contaminants.

Changing from the type of dry ice utilized, 3mm pellets (rice sized – see Fig. 2) to shaved block (sugar sized, .3mm, See Fig.3) therefore impacts the amount of the kinetic energy effect developed in the process. You'll note the greater flux density of the dry ice with the shaved block systems (Fig. 5), which allow for detailed cleaning in tight tolerance areas of the mold, over that of the 3mm pellets shown in Fig. 4. Not only are the smaller particles more effective than larger pellets in cleaning delicate substrates with integrate geometries or tiny openings, they also produce about 1,000 times more surface strikes for a given volume of ice [3]. This provides a more thorough surface coverage and faster removal rates on thinner contaminants.

The process and the equipment also provide various capabilities to adjust the Pellet Kinetic Effect. The most effect blasting angle, depending on the contaminant layer to be removed, for removal of coatings from medal is at an angle of 90 degrees (Spur 1999, Krieg 2008). Varying cleaning stand-off (working) distance, blast angle (nozzle to work surface), air pressure, dry ice feed rate can reduce blast aggressiveness and utilizing a different nozzle design.

Fragmenting dry ice particle size with the use of a Fragmenting Nozzle is also a common method to create a gentler clean. Fragmenting Nozzles can reduce a common 3mm particle size down to .6mm and a typical .3mm shaved block system particle down to snow. Fragmenting down to snow is very common for surface preparation to remove contaminants prior to painting or coating a molded part.

The dry ice particles have little hardness and are therefore non-abrasive to any substrate harder than dry ice. Studies, such as "Dry Ice Blasting for the Conservation Cleaning of Metals", Rozemarijn van der Molen, Ineke Joosten, Tonny Beentjes and Luc Megens, have shown that cleaning with dry ice does not damage most industrial substrates. Because the particles are relatively soft, the high velocity (V) (see Fig. 7) generated by patented single and multiple expansion reflection nozzle designs to generate the Pellet Kinetic Effect is key. The hardness of dry pellets was found to be 1.5-2.0 Mohs, which is soft compared to other forms of blast media [4]. (See Fig. 6, Krieg 2008).

Fig. 2 - 3mm Pellets

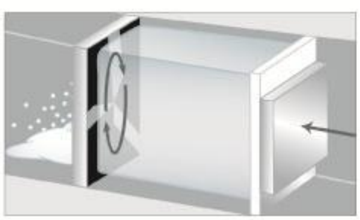


Fig. 3 - Shaved Block

Fig. 4 - 3mm dry ice

Fig. 5 – shaved block

Mohs Hardness Scale for Minerals

1 – Talc
2 – Gypsum, Dry Ice (Fingernail, Baking Soda ~ 2.5)
3 – Calcite (a penny)
4 – Fluorite (Corn Cob ~ 4.5)
5 – Apatite (Glass Beads & Nut Shells ~ 5.5)
6 – Orthoclase, Feldspar, Spectrolite (Steel File ~ 6.5-7.5)
7 – Quartz, Amethyst, Citrine, Agate (Garnet ~ 7.5)
8 – Topaz, Beryl, Emerald, Aquamarine
9 – Corundum, Ruby, Sapphire (Alum. Oxide ~ 8.5)
10- Diamond

Fig. 6 – Mohs Hardness Scale for Minerals

The Thermal Effect

The thermal effect is provided by a unique characteristic of dry ice – it is extremely cold, -79.5 degrees C (-109.3 degrees F). The inherently low temperature of dry ice aids removal of the contaminant. Its' low temperature causes the contaminant to embrittle and shrink, creating rapid micro-cracking and causing the bond between the contaminant and the substrate to fail.

This Thermal Effect causes a temperature gradient or Delta-T between the contaminate to be removed and the surface of the substrate material (Coefficient of Thermal Expansion and Contraction of dissimilar materials). Consequently, molds that are heated instead of cooled during normal processing (greater Delta-T) can improve and quicken the cleaning performance of dry ice.

Mark Krieg (2008) showed that the contribution of the thermal effect towards the overall cleaning effect was approximately 10% when blasting on an object at ambient temperature and up to 50% for an object heated to a temperature of 500 degree C.

Gas Expansion Effect

Another unique characteristic of dry ice is its ability to sublimate upon impact leaving no secondary waste or entrapment of blast media grit [5]. Upon impact, the $C0_2$ particles will sublimate or expand instantly and return to its natural gas state. During this phase transition from solid to gas, the volume (Vt) of dry ice expands up to 800 times and lifts the contaminate off of the substrate from the inside out. See Fig. 7. Mark Krieg showed that the sublimation effect of dry ice blasting was the least of the three cleaning principles. (Krieg 2008).

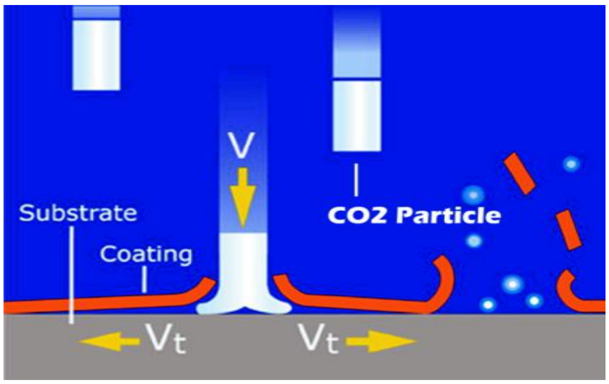


Fig. 7 – Kinetic, Thermal, Sublimation Properties of $C0_2$

Equipment and Process

The equipment typically utilized in the plastics industry are portable tabletop systems which sit on a portable cart and shaves a block of ice. Utility requirements are plant air (quick disconnect connection) of 80-90 psi consumed at rates of 12-50 scfm and 110/1/60 VAC connecting electrics. Other portable systems utilize systems use 3mm high density pellets and consume 50 - 165 scfm. Systems are available that utilize any form of dry ice available in the end-users marketplace, including scrap ice.

Sustainable: Clean, Green & Lean Process

Cleaning and deburring or deflashing with dry ice is a sustainable process. It conforms recognized definitions of sustainability, utilizing a recycled material, is a material that is found naturally in our environment, leaves no change or harm to the environment, is 100% recycled, and leaves 0% secondary waste.

The need for sustainable, environmental precision cleaning are driven by advancements in manufacturing productivity and quality, the tight tolerances and integrate geometries of tooling (i.e.: LSR molds), the evolving environmental protection and worker safety legislation and the need to reduce costs. Precision cleaning under these more difficult constraints requires technology that provides improved performance, productivity, environmental quality and economics, all while adapting to rapidly evolving manufacturing technology. In response to these new pressures, dry ice cleaning processes have emerged to prevent malfunctions in high-reliability applications, necessitating a green process solution. After more than 25 years of commercial development, the technology is equipped to meet new, more demanding complex cleaning challenges, today and into the future.

Clean

Clean molds are a critical component of producing quality end products. Dry ice cleaning produces a superior clean which improves the quality of finished goods. Dry ice is able to clean better than with traditional methods incorporating solvents and without leaving any chemical residue which often finds itself on the next few molded parts. Dry ice does not create any secondary waste – it simply returns to its natural gas state upon impact.

It utilizes the same food grade CO_2 used in carbonated beverages. It is a dry process which is non-corrosive, non-conductive, non-abrasive and leaves no secondary residue.

Green

A major consideration for any cleaning application should be the impact that it has on the environment, as well as any risks that it may present to workers. The dry ice cleaning process is an environmentally responsible process. It uses a recycled product that disappears as you use it.

The CO_2 utilized for dry ice cleaning is reclaimed CO_2 from refining industries and does not contribute to the greenhouse effect. It is colorless, tasteless, odorless, non-toxic, non-poisonous and food safe. It eliminates the use of harmful and ozone depleting cleaning chemicals.

There is no secondary waste stream to be cleaned up and disposed of, assisting those striving for zero-landfill goals. Health risks are reduced and operator safety enhanced due to the significant decrease in exposure to hazardous chemical agents and dangerous cleaning methods, resulting in a much safer work environment.

Unique benefits derived from using a bio-based cleaning process include conservation of water, reduced energy consumption, elimination of the use of chemicals and solvents and a reduction in industrial $C0_2$ emissions.

Evolving environmental and employee safety concerns have prompted more stringent awareness of commonly accepted industry cleaning methods that result in environmentally harmful secondary waste. Solvents spilling into local waterways, employee exposure to cleaners and mold wear due to traditional methods are all reasons to consider cleaning with dry ice.

Moreover, $C0_2$-based cleaning technology is a positive contribution to hazardous air pollutant (HAP), volatile organic compound (VOC), and greenhouse gas (GHG) emissions reduction strategies [6]. Substituting traditional solvent and aqueous processes with bio-based agents reduces pollution, conserves energy and eliminates manufacturing waste.

It is also meaningful to consider that our production processes, including the method and what we use when we clean our tooling, affect not only the environment but also the bottom line. Transitioning to sustainable and ecologically sensitive cleaning solutions should be the goal of everyone in the plastics industry especially when implementing such best industry practice solutions that offer increased quality and productivity.

Lean

A common problem in the molding industry is that manual mold cleaning is very labor intensive. It involves using cloth wipes, solvents and chemicals. Often times the manual process is ineffective due to small areas, vents and inaccessible areas. Dry ice cleaning technology increases manpower efficiency, reduces waste and cost and compliments process improvement initiatives, such as 5S, Six Sigma, and Total Productive Management (TPM).

Processors are trying to get the most out of their equipment, emphasizing the need to maximize up-time, decrease downtime and prevent emergency or unscheduled stops, which is the main goal behind TPM. Downtime that was once measured in hours, sometimes even days, is now measured in minutes. This technology increases manpower efficiency, reduces waste and cost and compliments process improvement initiatives by allowing the molds to be spot cleaned while still in the press.

Given the competitive nature of the molding environment, companies are being asked to do more with less. Companies are working with smaller budgets and performing maintenance activities (including cleaning) with fewer people. The quality of the cleaning is often equivalent to the quality of the process. When maintenance is guided by the principles of TPM, rather than simply a necessary evil, it becomes a fundamental means to reduce waste, produce high quality parts, reduce costs and eliminate defects due to dirty molds.

Cleaning with dry ice is commonly 4-6 times faster than traditional cleaning methods resulting in the reduction of waste and costs. It extends production runs, prevents unnecessary downtime, cleaning molds hot and in-place. Traditional cleaning methods can be time consuming, ineffective, and costly.

Steve Johnson at ToolingDocs recently published an article demonstrating the Correction Action Report from a 20-press medical molder that targeted and made great strides in reducing total defects. He reported that when defect frequency drops, so do corrective actions, but the percentage of cleaning time (~66%) stays the same. The reason noted was that most cleaning was still being done manually. [7]

When looking at cleaning and associated costs, processors have to look beyond the simple materials used in cleaning their mold. Labor is a major factor, as is the downtime of the equipment and lost production. Simply saving 15 minutes/day/machine can improve the profitability of a molding facility.

The Yearly Cost of Wasting 15 Minutes per Day/Machine

Machine Hourly Rate ($/Hour)	Number of Machines						
	5	10	15	20	30	40	50
	Dollars ($) Lost per Year						
$20	$6,375	$12,750	$19,125	$25,500	$38,250	$51,000	$63,750
$30	$9,563	$19,125	$28,688	$38,250	$57,375	$76,500	$95,625
$40	$12,750	$25,500	$38,250	$51,000	$76,500	$102,000	$127,500
$50	$15,938	$31,875	$47,813	$63,750	$95,625	$127,500	$159,375
$70	$22,313	$44,625	$66,938	$89,250	$133,875	$178,500	$223,125
$90	$28,688	$57,375	$86,063	$114,750	$172,125	$229,500	$286,875
$110	$35,063	$70,125	$105,188	$140,250	$210,375	$280,500	$350,625

Note: Data based on an 8-hour day, 255 working days/year.

Fig. 8 – Cost of wasting 15 minutes chart

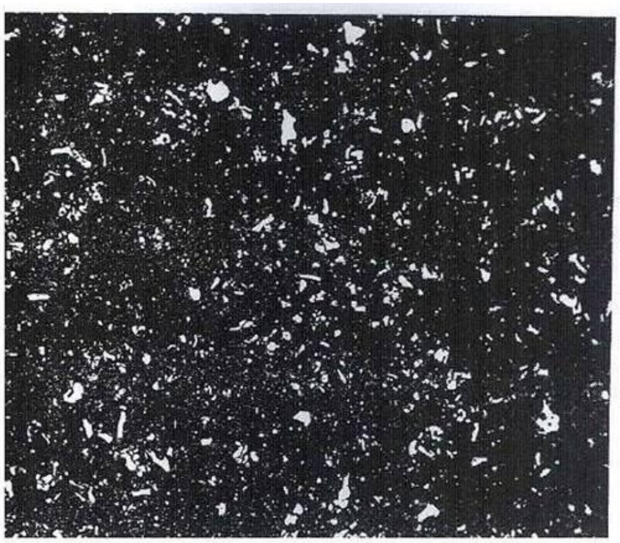
Non-abrasive/corrosive/conductive/combustible

Most would agree that the mold is the heart of the molding process. No matter how good of a molding machine you utilize, if the mold is worn, you cannot produce good quality parts.

Traditional cleaning often utilizes methods which can wear the mold. Those methods often involve the use of chemicals or media which are abrasive and/or can leave grit entrapment causing further cleaning issues. Clearances on molds with tight dimensional tolerances (i.e. LSR tooling) are often worn away with traditional cleaning methods – shutoffs, parting lines, rolling over edges, wear to vents and other tight tolerance areas can all lead to flash problems. Over time, traditional cleaning methods can reduce the asset life of the mold. Unfortunately, to clean it is to destroy it, is the resultant of many cleaning methods.

When molds are not cleaned properly and on regularly, the final product can contain blemish and unwanted flash due to the residue of plastic compound which builds up in the injection molds. Left unchecked, it can create filling problems which lead to quality problems and increased production cycle times. It is noted by ToolingDocs that cleaning techniques is a contributor to mold wear [8].

Dry ice will not etch, profile or change dimensions of substrates harder than dry ice. It is successfully utilized to clean common tooling substrates such as P-20, 4140, tool steel, 420 stainless steel, highly polished surfaces (A1 and various VDI). It can clean delicate substrates such as chrome and nickel plated tools, ceramic coatings, aluminum (QC-10, Alumold 500, Hokotol), and brass alloys. Tests have been run on a stainless steel (440C) mold to verify that cleaning with dry ice did not damage the edge of the molds or modify the structure of the steel [9]. Micrographic examination of the metallurgical structures of the molds show that the presence of the carbide particles are were unaltered at both the core and the surface after cleaning with dry ice [10].



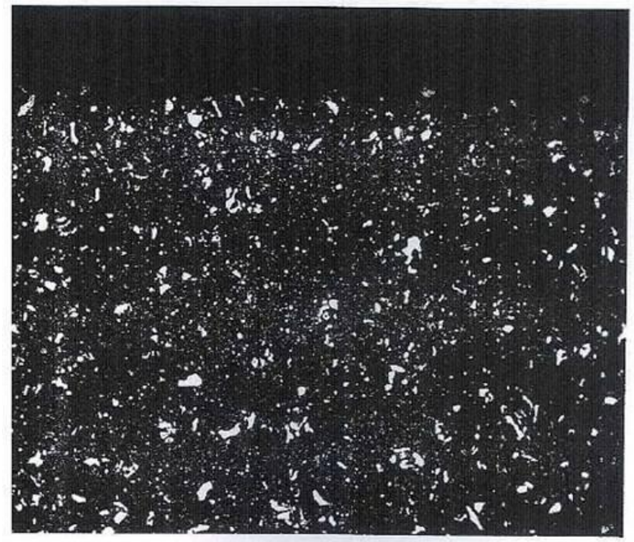


Fig. 9 – Unaltered carbide particles after cleaning

The process is also dry so it is commonly utilized to clean sensors, motors, wire, hot runner junction boxes, etc.

Applications and Results

In –Machine Mold Cleaning

One of the challenges that molders face is molds fouling or soiling because of the off-gassing of the various resins or resin additives on the cavities (causing quality issues) at the vent area (causing processing issues) and the subsequent productivity loss when molds are taken out of the press for cleaning. It is not uncommon for 6-8 hours to be lost when removing and cleaning using traditional cleaning methods. In some applications, additional time would also be required to reheat the mold to production temperatures before the molding processes could resume.

Shutting down the press is costly. Moving hot molds (often exceeding 200^{o} C in rubber and thermoset applications) from one location to another for cleaning is time consuming and risky, both in terms of worker safety and potential damage to molds removal, disassembly, reassembly and reinstallation into the press. Dry ice cleaning methods allow molders to clean critical areas of their molds in the machine, at operating temperatures without creating any secondary waste.

Operators roll the portable equipment to the press and clean the mold cavities and vents at operating temperatures (see Fig. 11 & 12). Subsequent photos show the before and after pictures of mold cavities and vents that had been soiled with off-gassing (see Fig. 13, 14)

The cleaning solutions run the gamut of various molding applications:

Packaging - Injection molded 72-cavity PET performs used to take 3 hours to clean – clean time reduced to less than 45 minutes. Mike Urquhart, VP of PET Husky, notes that "preform mold cleaning can be a time-consuming process, particularly for high-cavitation molds. Dry ice blasting definitely results in a superior clean, and with less downtime. We have been able to increase production. The detail of cleaning we get with Cold Jet systems allows us to clean areas that otherwise could not be cleaned". See figure 10 for the areas cleaned on a typical preform mold.

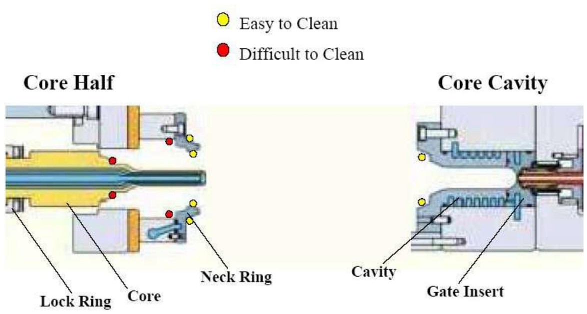


Fig. 10 – Areas to clean on a typical PET preform mold

Automotive - An automotive interior molder reduced scrap and maintained gloss levels utilizing dry ice cleaning. They were able to eliminate the use of chemical solutions and wire brushes, resulting in a faster and more effective clean in some very tight areas. Employee health and safety concerns were eliminated and production time was saved.

An American automotive company cleaning molds for seats used to clean the tools every two weeks by turning their ovens up to "unsafe" levels to melt excess wax which had accumulated in the mold. The labor costs directly attributable to this process amounted to $135,000 annually. Cleaning with dry ice systems reduced that figure by almost 70%.

Medical - A medical manifold manufacturer would disassemble its molds, let them soak in oven cleaner and then scrub them to remove buildup.

A catheter tip manufacturer used isopropyl alcohol and brushes to clean the part's small mold cavities. The process was slow and labor intensive, often inconsistent and inadequate.

Technical - A leading thermoplastic and LSR molder reduced cleaning time by 75% and cleaning crew resources by 60%.

One rubber molder was losing 6-8 hours of production for mold removal, cleaning and reinstallation of the tool. Utilizing dry ice cleaning systems reduced cleaning time to just 30-60 minutes. Dry ice cleaning extends production runs, prevents unnecessary downtime, by allowing for cleaning molds hot and in-place.

Blown Film – cleaning the tower (sizing cage and collapsing frame) of a slip agent, added to the base resin to increase throughput, is a common application for dry ice cleaning. The slip agent off-gasses and leaves a waxy substance on the downstream equipment.

Extrusion – cleaning the embossing rolls of sheet lines is a common application for dry ice cleaning.

Fig. 11 – In-Machine mold cleaning photo

Fig 12 – In-Machine mold cleaning photo

Fig. 13 – Off-gassing clogging the vent area (before photo)

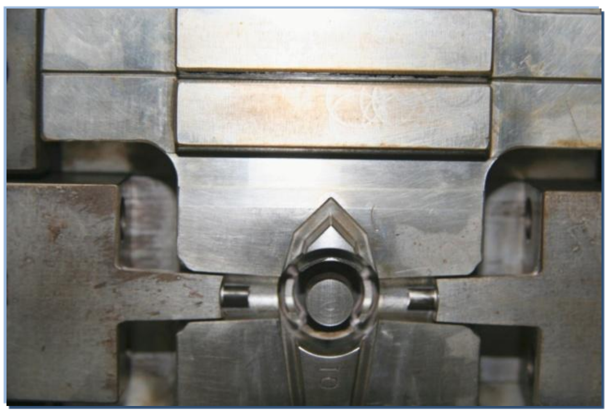


Fig. 14 – After photo of mold vent area

Deburring and Deflashing

Automation cells are often deployed to deburr machined plastic parts. They are also integrated into the machining cycles as well on sub-spindles of CNC equipment.

Fig. 15 – Before photo of PEEK part flash

One major American automotive company reduced the labor content for deflashing a RIM bumper by 75% and reduced cycle time from 5.18 minutes to 2.32 minutes per bumper. This translated into over $2.0 million in annual cost savings.

Another manufacturer utilized dry ice to remove excess foil flash from a cell phone after an in-mold decorating process.

Conclusion

Manufacturing engineers, process engineers, plant managers, and maintenance managers are under constant pressure to reduce costs, make their facilities more efficient and do more with less. Traditionally, maintenance has been viewed as a process that simply had to be done by any means necessary. Today, proven lean manufacturing management methodologies, such as 5S and TPM, are encouraging organizations to embrace maintenance as a critical business function. Doing so brings maintenance under the magnifying glass, providing companies an opportunity to truly evaluate and improve upon their conventional cleaning methods and processes.

The excellent cleaning capability of cleaning with dry ice while the mold is still in the press is a positive step to make quality and productivity gains in the plastics industry. Cleaning with dry ice is an effective, environmentally responsible solution to allow processors to do more with less time, less resources and with less impact on production.

Acknowledgements

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Keywords

Dry Ice, CO_2, cleaning, mold cleaning, deburr, deflash