Advanced Troubleshooting Guide

Root Cause Analysis

DEMHA CONSULTANTS

The Professional Engineers

Content

[1]STOP – Systematically Think Observe Proceed (Approach)

Why a guide dedicated to troubleshooting?

The answer to that lies in frustrations that the authors have experienced over the years in launching and maintaining machineries and processes.

Have you ever experienced any of the following?

High scrap rates, Excess down time, Slow cycle times, Customer rejections (both internal and external), Processing around tooling issues, Damage to molds, Defects that seem to show up out of nowhere, Defects that keep reoccurring, 'Fixed' problems that keep coming back, Molds that run fine in one machine but not in another (IPS)

What's the key difference in this troubleshooting guide?

The key differences come down to the efforts to bridge the gaps between tooling, processing, and materials and provide in- depth feedback from designing, building, processing and maintaining the systems.

What's the note taken?

As you move down the troubleshooting road keep learning, always ask why, never assume, and stay open minded!

A reference study: Kilimanjaro Industrial Park (Beverage and Rigid)

Editor: Ahmed H. H. Mansoor – Founder, DEMHA Group

1. Introduction

Troubleshooting is problem solving. Most troubleshooters are called upon to resolve problems with the parts of the machine, or process [1]. There are many problems encountered in the process including these general categories:

1. Material defects
2. Dimensional problems
3. Part breakage
4. Long cycle times
5. High scrap rate

All of the above lead to increased cost to manufacture a disrupted part, which often makes the difference between profit and loss [2, 3]. An operation that is consistently running high scrap or long cycles is going to struggle to succeed.

2. 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 [4, 5].

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 guide is intended to help convey some of the knowledge that the authors have learned through many years of troubleshooting [6, 7]. Some of the key things that will help anyone improve at troubleshooting include:

1. *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.
2. *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.
3. *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.
4. *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.
5. *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.

6. *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.
7. *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.
8. *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.

3. 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:

1. 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.
2. 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.
3. 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.
4. 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 guide aims to help provide some tools that can make troubleshooting more efficient and hopefully help people wisely use their time spent in troubleshooting [8, 9].

4. Troubleshooting Methodology

As mentioned in the effective troubleshooter syntax, 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.

5. 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 quadrupled why questions and answers 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 [10]. The concept of STOP troubleshooting came about as an easy way to train people in the methodology of troubleshooting.

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 [11].

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. Considering the plastic section as the mother plant of our core beverage section in Jambo Food Products. For systematic injection molding troubleshooting the ***4M's*** that need focus on are: Molding process, Mold, Machine and 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 any troubleshooting guide 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 [12].

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 in the plastic section. 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 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.

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 [13].

Sometimes in the think step of troubleshooting it is necessary to think outside of the box. Many problems encountered in processing 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 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.

STOP: Observe

Observation is critical to solving problems. Much like Sherlock Holmes, a good engaging 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 critical machine subject to fault. 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 raw material 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 disruptive process, a walk around the machine is usually a good practice. A quick walk can often highlight a concern that must be addressed.

For the case of Plastic Section, i.e. the IPS and CCM machines, 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.

The figure below 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 troubleshooters 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 [14].

S/N	4M Basic 8	Y/N
*	**Molding Procees**	*
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?	

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. The figure below 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.

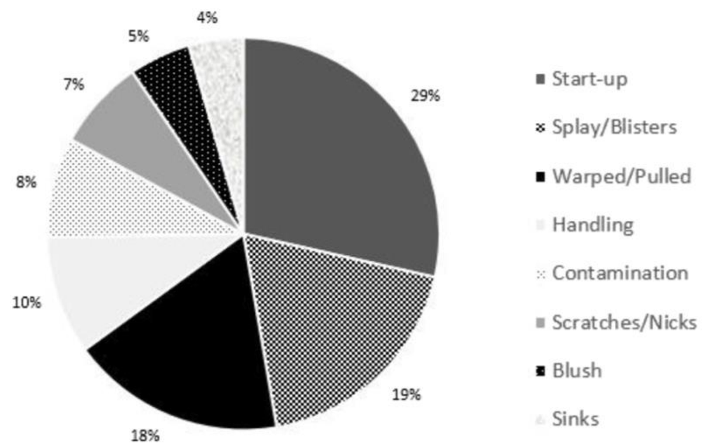

Figure 1: Pie chart breakdown of scrap percentage

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. The figure below 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.

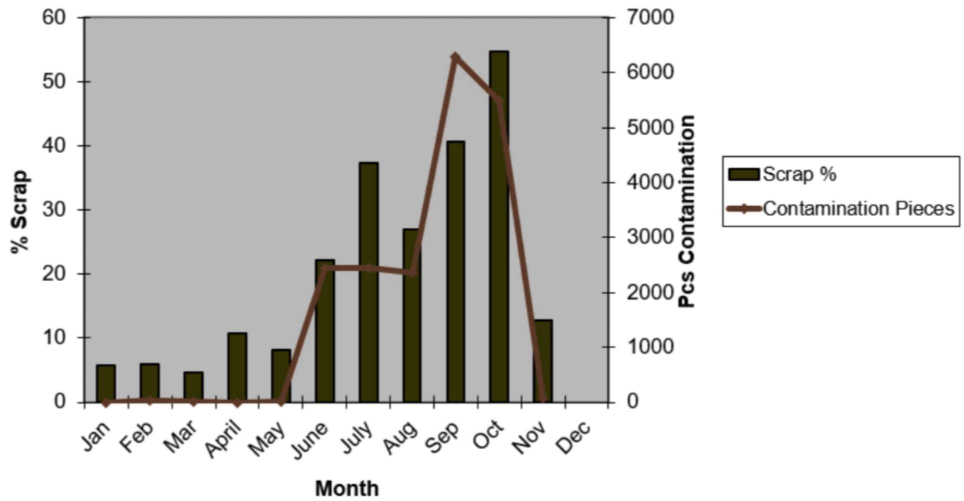

Figure 2: A sudden increase in scrap and a corresponding sudden drop off scrap after a resolve

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*** and ***Material variation***

6. Tips for energy efficiency in electrical utilities (272 Ahmed's Way)

Electricity

1. Optimize the tariff structure with utility supplier.
2. Schedule your operations to maintain a high load factor.
3. Shift loads to off-peak times if possible.
4. Minimize maximum demand by tripping loads through a demand controller.
5. Stagger start-up times for equipment with large starting currents to minimize load peaking.
6. Use standby electric generation equipment for on-peak high load periods.
7. Correct power factor to at least 0.90 under rated load conditions.
8. Relocate transformers close to main loads.
9. Set transformer tans to optimum settings.
10. Disconnect primary power to transformers that do not serve any active loads.
11. Consider on-site electric generation or cogeneration.
12. Export power to grid it you have any surplus in your captive generation.
13. Check utility electric meter with your own meter.
14. Shut off unnecessary computers, printers, and copiers at night.

Motors

15. Properly size to the load for optimum efficiency. (High efficiency motors offer of 4 - 5% higher efficiency than standard motors)
16. Use energy-efficient motors for economical purposes.
17. Use synchronous motors to improve power factor.
18. Check alignment.
19. Provide proper ventilation. (For every 10°C increase in motor operating temperature over recommended peak. the motor life is estimated to be halved)
20. Check for under-voltage and over-voltage conditions.
21. Balance the three-phase power supply. (An imbalanced voltage can reduce 3 - 5% in motor input power)
22. Demand efficiency restoration after motor rewinding. (If rewinding is not done properly, the efficiency can be reduced by 5 - 8%)

Drives

23. Use variable-speed drives for large variable loads.
24. Use high-efficiency gear sets.
25. Use precision alignment.
26. Check belt tension regularly.
27. Eliminate variable-pitch pulleys.
28. Use flat belts as alternatives to v-belts.
29. Use synthetic lubricants for large gearboxes.
30. Eliminate eddy current couplings.
31. Shut them off when not needed.

Fans

32. Use smooth, well-rounded air inlet cones for fan air intakes.
33. Avoid poor flow distribution at the fan inlet.

34. Minimize tan inlet and outlet obstructions.
35. Clean screens, filters, and fan blades regularly.
36. Use aerofoil-shaped fan blades.
37. Minimize fan speed.
38. Use low-slip or flat belts.
39. Check belt tension regularly.
40. Eliminate variable pitch pulleys.
41. Use variable speed drives for large variable fan loads.
42. Use energy-efficient motors for continuous or near-continuous operation.
43. Eliminate leaks in ductwork.
44. Minimise bends in ductwork.
45. Turn fans off when not needed.

Blowers

46. Use smooth, well-rounded air inlet ducts or cones for air intakes.
47. Minimize blower inlet and outlet obstructions.
48. Clean screens and filters regularly.
49. Minimize blower speed.
50. Use low-slip or no-slip belts.
51. Check belt tension regularly.
52. Eliminate variable pitch pulleys.
53. Use variable speed drives for large variable blower loads.
54. Use energy-efficient motors for continuous or near-continuous operation.
55. Eliminate ductwork leaks.
56. Turn blowers off when they are not needed.

Pumps

57. Operate pumping near best efficiency point.
58. Modify pumping to minimize throttling.
59. Adapt to wide load variation with variable speed drives or sequenced control of smaller units.
60. Stop running both pumps - - add an auto-start for an on-line spare or add a booster pump in the problem area.
61. Use booster pumps for small loads requiring higher pressures.
62. Increase fluid temperature differentials to reduce pumping rates.
63. Repair seals and packing to minimize water waste.
64. Balance the system to minimize flows and reduce pump power requirements.
65. Use siphon effect to advantage: don't waste pumping head with a free-fall (gravity) return.

Compressors

66. Consider variable speed drive for variable load on positive displacement compressors.
67. Use a synthetic lubricant if the compressor manufacturer permits it.
68. Be sure lubricating oil temperature is not too high, (oil degradation and lowered viscosity) and not too low (condensation contamination)

69. Change the oil filter regularly.
70. Periodically inspect compressor intercoolers for proper functioning.
71. Use waste heat from a very large compressor to power an absorption chiller or preheat process or utility feeds.
72. Establish a compressor efficiency-maintenance program. Start with an energy audit and follow-up then make a compressor efficiency-maintenance program a part of your continuous energy management program.

Compressed air

73. Install a control system to coordinate multiple air compressors.
74. Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple air compressors.
75. Avoid over sizing -- match the connected load.
76. Load up modulation-controlled air compressors. (They use almost as much power at partial load as at full load)
77. Turn off the back-un air compressor until it is needed.
78. Reduce air compressor discharge pressure to the lowest acceptable setting. (Reduction of 1 kg/cm^2 air pressure (8 kg/cm^2 to 7 kg/cm^2 would result in 9% input power savings. This will also reduce compressed air leakage rates by 10%)
79. Use the highest reasonable dryer dew point settings.
80. Turn off refrigerated and heated air dryers when the air compressors are off.
81. Use a control system to minimize heatless desiccant dryer purging.
82. Minimize purges. Leaks, excessive pressure drops, and condensation accumulation (Compressed air leak from 1 mm hole size at 7 kg/cm^2 pressure would mean power loss equivalent to 0.5 kW)
83. Use drain controls instead of continuous air bleeds through the drains.
84. Consider engine-driven or steam-driven air compression to reduce electrical demand charges.
85. Replace standard v-belts with high-efficiency flat belts as the old v-belts wear out.
86. Use a small air compressor when major production load is off.
87. Take air compressor intake air from the coolest (but not air conditioned) location (Every 5°C reduction in intake air temperature would result in 1% reduction in compressor power consumption)
88. Use an air-cooled after-cooler to heat building makeup air in winter.
89. Be sure that heat exchangers are not fouled (e.g. -- with oil).
90. Be sure that air/oil separators are not fouled.
91. Monitor pressure drops across suction and discharge filters and clean or replace filters promptly upon alarm.
92. Use a properly sized compressed air storage receiver. Minimize disposal costs by using lubricant that is full demulsible and an effective oil-water separator.
93. Consider alternatives to compressed air such as blowers for cooling, hydraulic rather than air cylinders, electric rather than air actuators, and electronic rather than pneumatic controls.
94. Use nozzles or venturi-type devices rather than blowing with open compressed air lines.
95. Check for leaking drain valves on compressed air filter/regulator sets. Certain rubber-type valves may leak continuously after they age and crack.
96. In dusty environments. control packaging lines with high-intensity photocell units instead of standard units with continuous air purging of lenses and reflectors.

97. Establish a compressed air efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressed air efficiency-maintenance program a part of your continuous energy management program.

Chillers

98. Increase the chilled water temperature set point if possible.
99. Use the lowest temperature condenser water available that the chiller can handle (Reducing condensing temperature by 5.5°C, results in a 20 - 25% decrease in compressor kWhr)
100. Increase the evaporator temperature (5.5°C increase in evaporator temperature reduces compressor power consumption by 20 – 25%)
101. Clean heat exchangers when fouled (1 mm scale build-up on condenser tubes can increase energy consumption by 40%)
102. Optimize condenser water flow rate and refrigerated water flow rate.
103. Replace old chillers or compressors with new higher-efficiency models.
104. Use water-cooled rather than air-cooled chiller condensers.
105. Use energy-efficient motors for continuous or near-continuous operation.
106. Specify appropriate fouling factors for condensers.
107. Do not overcharge oil.
108. Install a control system to coordinate multiple chillers.
109. Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple chillers.
110. Run the chillers with the lowest operating costs to serve base load.
111. Avoid oversizing -- match the connected load.
112. Isolate off-line chillers and cooling towers.
113. Establish a chiller efficiency-maintenance program. Start with an energy audit and follow-up, then make a chiller efficiency-maintenance program a part of your continuous energy management program.

HVAC (Heating / Ventilation / Air Conditioning)

114. Tune up the HVAC control system.
115. Consider installing a building automation system (BAS) or energy management system (EMS) or restoring an out-of-service one.
116. Balance the system to minimize flows and reduce blower/fan/pump power requirements.
117. Eliminate or reduce reheat whenever possible.
118. Use appropriate HVAC thermostat setback.
119. Use morning pre-cooling in summer, pre-heating in winter (before electrical peak hours).
120. Use building thermal lag to minimize HVAC equipment operating time.
121. In winter during unoccupied periods, allow temperatures to fall as low as possible without freezing water lines or damaging stored materials.
122. In summer during unoccupied periods, allow temperatures to rise as high as possible without damaging stored materials.
123. Improve control and utilization of outside air.
124. Use air-to-air heat exchangers to reduce energy requirements for heating and cooling of outside air.
125. Reduce HVAC system operating hours (e.g. -- night, weekend).

126.	Optimize ventilation.
127.	Ventilate only when necessary. To allow some areas to be shut down when unoccupied, install dedicated HVAC systems on continuous loads (e.g. -- computer rooms).
128.	Provide dedicated outside air supply to kitchens, cleaning rooms, combustion equipment, etc. to avoid excessive exhausting of conditioned air.
129.	Use evaporative cooling in dry climates.
130.	Reduce humidification or dehumidification during unoccupied periods.
131.	Use atomization rather than steam for humidification where possible.
132.	Clean HVAC unit coils periodically and comb mashed fins.
133.	Upgrade filter banks to reduce pressure drop and thus lower fan power requirements.
134.	Check HVAC filters on a schedule (at least monthly) and clean/change if appropriate.
135.	Check pneumatic controls air compressors for proper operation. cycling, and maintenance
136.	Isolate air-conditioned loading dock areas and cool storage areas using high-speed doors or clear PVC strip curtains.
137.	Install ceiling fans to minimize thermal stratification in high-bay areas.
138.	Relocate air diffusers to optimum heights in areas with high ceilings.
139.	Consider reducing ceiling heights.
140.	Eliminate obstructions in front of radiators baseboard heaters. etc.
141.	Check reflectors on infrared heaters for cleanliness and proper beam direction.
142.	Use professionally designed industrial ventilation hoods for dust and vapor control.
143.	Use local infrared heat for personnel rather than heating the entire area.
144.	Use spot cooling and heating (e.g. -- use ceiling fans for personnel rather than cooling the entire area)
145.	Purchase only high-efficiency models for HVAC window units.
146.	Put HVAC window units on timer control.
147.	Don't oversize cooling units. (Oversized units will "short cycle" which results in poor humidity control)
148.	Install multi-fueling capability and run with the cheapest fuel available at the time.
149.	Consider dedicated make-up air for exhaust hoods. (Why exhaust the air conditioning or heat if you don't need to?)
150.	Minimize HVAC fan speeds.
151.	Consider desiccant drying of outside air to reduce cooling requirements in humid climates.
152.	Consider ground source heat pumps.
153.	Seal leaky HVAC ductwork.
154.	Seal all leaks around coils.
155.	Repair loose or damaged flexible connections (including those under air handling units).
156.	Eliminate simultaneous heating and cooling during seasonal transition periods.
157.	Zone HVAC air and water systems to minimize energy use.
158.	Inspect. clean. lubricate. and adjust damper blades and linkages.

159.	Establish an HVAC efficiency – maintenance program. Start with an energy audit and follow-up, then make an HVAC efficiency – maintenance program a part of your continuous energy management program.

Refrigeration

160.	Use water-cooled condensers rather than air-cooled condensers.
161.	Challenge the need for refrigeration. particularly for old batch processes.
162.	Avoid oversizing -- match the connected load.
163.	Consider gas-powered refrigeration equipment to minimize electrical demand charges.
164.	Use "free cooling" to allow chiller shutdown in cold weather.
165.	Use refrigerated water loads in series if possible.
166.	Convert firewater or other tanks to thermal storage.
167.	Don't assume that the old way is still the best -- particularly for energy-intensive low temperature systems.
168.	Correct inappropriate brine or glycol concentration that adversely affects heat transfer and/ or pumping energy. If it sweats, insulate it, but if it is corroding, replace it first.
169.	Make adjustments to minimize hot gas bypass operation.
170.	Inspect moisture/liquid indicators.
171.	Consider change of refrigerant type it it will improve efficiency.
172.	Check for correct refrigerant charge level.
173.	Inspect the purge for air and water leaks.
174.	Establish a refrigeration efficiency-maintenance program. Start with an energy audit and follow-up, then make a refrigeration efficiency-maintenance program a part of your continuous energy management program.

Cooling towers

175.	Control cooling tower tans based on leaving water temperatures.
176.	Control to the optimum water temperature as determined from cooling tower and chiller performance data.
177.	Use two-speed or variable-speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on-off control if there are many.
178.	Turn off unnecessary cooling tower fans when loads are reduced.
179.	Cover hot water basins to minimize algae growth that contributes to fouling.
180.	Balance flow to cooling tower hot water basins.
181.	Periodically clean plugged cooling tower water distribution nozzles.
182.	Install new nozzles to obtain a more-uniform water pattern.
183.	Replace splash bars with self-extinguishing PVC cellular-film fill.
184.	On old counterflow cooling towers, replace old spray-type nozzles with new square-spray ABS practically non-clogging nozzle.
185.	Replace slat-type drift eliminators with high-efficiency, low-pressure-drop, self-extinguishing, PVC cellular units.
186.	If possible, follow manufacturer's recommended clearances around cooling towers and relocate or modify structures, signs, fences, dumpsters, etc. that interfere with air intake or exhaust.
187.	Optimize cooling tower fan blade angle on a seasonal and/or load basis.

188.	Correct excessive and/or uneven fan blade tip clearance and poor fan balance.
189.	Use a velocity pressure recovery fan ring.
190.	Divert clean air-conditioned building exhaust to the cooling tower during hot weather.
191.	Re-line leaking cooling tower cold water basins.
192.	Check water overflow pipes for proper operating level.
193.	Optimize chemical use.
194.	Consider side stream water treatment.
195.	Restrict flows through large loads to design values.
196.	Shut off loads that are not in service.
197.	Take blowdown water from the return water header.
198.	Optimize blowdown flow rate
199.	Automate blowdown to minimize 1t
200.	Send blowdown to other uses (Remember, the blowdown does not have to be removed at the cooling tower. It can be removed anywhere in the piping system.)
201.	Implement a cooling tower winterization plan to minimize ice build-up.
202.	Install interlocks to prevent tan operation when there is no water flow.
203.	Establish a cooling tower efficiency-maintenance program. Start with an energy audit and follow-up. then make a cooling tower efficiency-maintenance program a part of your continuous energy management program.

Lighting

204.	Reduce excessive illumination levels to standard levels using switching, decamping, etc (Know the electrical effects before doing decamping.)
205.	Aggressively control lighting with clOcK timers, delay timers, photocells, and/or occupancy sensors
206.	Install efficient alternatives to incandescent lighting, mercury vapor lighting, etc. Efficiency (lumens/watt) of various technologies range from best to worst approximately as follows: low pressure sodium, high pressure sodium, metal halide, fluorescent, mercury vapor, incandescent.
207.	Select ballasts and lamps carefully with high power factor and long-term efficiency.
208.	Upgrade obsolete fluorescent systems to Compact fluorescents and electronic ballasts.
209.	Consider lowering the fixtures to enable using less of them.
210.	Consider daylighting, skylights, etc.
211.	Consider painting the walls a lighter color and using less lighting fixtures or lower wattages.
212.	Use task lighting and reduce background illumination.
213.	Re-evaluate exterior lighting strategy, type, and control. Control it aggressively.
214.	Change exit signs from incandescent to LED.

DG Sets

215.	Optimize loading.
216.	Use waste heat to generate steam/hot water / power an absorption chiller or preheat process or utility feeds.
217.	Use jacket and head cooling water for process needs.

218.	Clean air filters regularly.
219.	Insulate exhaust pipes to reduce DG set room temperatures.
220.	Use cheaper heavy fuel oil for capacities more than 1MW.

Buildings

221.	Seal exterior cracks/openings/gaps with caulk, casketing, weatherstripping, etc.
222.	Consider new thermal doors, thermal windows, rooting insulation, etc.
223.	Install windbreaks near exterior doors.
224.	Replace single-pane glass with insulating glass.
225.	Consider covering some window and skylight areas with insulated wall panels inside the building.
226.	If visibility is not required but light is required, consider replacing exterior windows with insulated glass block.
227.	Consider tinted glass, reflective glass, coatings, awnings, overhangs, draperies, blinds, and shades for sunlit exterior windows.
228.	Use landscaping to advantage.
229.	Add vestibules or revolving doors to primary exterior personnel doors.
230.	Consider automatic doors, air curtains, strip doors, etc. at high-traffic passages between conditioned and non-conditioned spaces. Use self-closing doors if possible.
231.	Use intermediate doors in stairways and vertical passages to minimize building stack effect.
232.	Use dock seals at shinDing and receiving doors.
233.	Bring cleaning personnel in during the working day or as soon alter as possible to minimize lighting and HVAC costs.

Water and Wastewater

234.	Recycle water, particularly for uses with less-critical quality requirements.
235.	Recycle water, especially if sewer costs are based on water consumption.
236.	Balance closed systems to minimize flows and reduce pump power requirements.
237.	Eliminate once-through cooling with water.
238.	Use the least expensive type of water that will satisfy the requirement.
239.	Fix water leaks.
240.	Test for underground water leaks. (It's easy to do over a holiday shutdown.)
241.	Check water overflow pipes for proper operating level.
242.	Automate blowdown to minimize it.
243.	Provide proper tools for wash down -- especially self-closing nozzles.
244.	Install efficient irrigation.
245.	Reduce flows at water sampling stations.
246.	Eliminate continuous overflow at water tanks.
247.	Promptly repair leaking toilets and faucets.
248.	Use water restrictors on faucets. showers. etc
249.	Use self-closing type faucets in restrooms.
250.	Use the lowest possible hot water temperature.
251.	Do not use a heating system hot water boiler to provide service hot water during the cooling season -- Install a smaller. more-efficient system for the cooling season service not water.

252.	If water must be heated electrically, consider accumulation in a large, insulated storage tank to minimize heating at on-peak electric rates.
253.	Use multiple, distributed, small water heaters to minimize thermal losses in large piping systems.
254.	Use freeze protection valves rather than manual bleeding of lines.
255.	Consider leased and mobile water treatment systems. especially for deionized water.
256.	Deal sumps to prevent seepage inward from necessitating extra sump bump operation.
257.	Install pretreatment to reduce TOC and BOD surcharges.
258.	Verify the water meter readings. (You'd be amazed how long a meter reading can be estimated after the meter breaks or the meter bit his with water!)
259.	Verify the sewer flows if the sewer bills are based on them.

Miscellaneous

260.	Meter any unmetered utilities. Know what normal efficient use is. Track down causes of deviations.
261.	Shut down spare, idling, or unneeded equipment.
262.	Make sure that all of the utilities to redundant areas are turned off -- including utilities like compressed air and cooling water.
263.	Install automatic control to efficiently coordinate multiple air compressors, chillers. cooling tower.
264.	Renegotiate utilities contracts to reflect current loads and variations.
265.	Consider buying utilities from neighbors, particularly to handle peaks.
266.	Leased space often has low-bid inefficient equipment. Consider upgrades if your lease will continue for several more years.
267.	Adjust fluid temperatures within acceptable limits to minimize heat in pipelines.
268.	Minimize use of flow bypasses and minimize bypass flow rates.
269.	Provide restriction orifices in purges (nitrogen, steam, etc.)
270.	Eliminate unnecessary flow measurement orifices.
271.	Consider alternatives to high pressure drops across valves.
272.	Turn off winter heat tracing that is on in summer.

Checklist for energy efficiency in thermal utilities (63 Ahmed's Way)

Boilers

1.	Preheat combustion air with waste heat. (22 "C reduction in flue gas temperature increases boiler efficiency by 1%)
2.	Use variable speed drives on large boiler combustion air fans with variable flows.
3.	Burn wastes if permitted.
4.	Insulate exposed heated oil tanks.
5.	Clean burners, nozzles, strainers, etc.
6.	Inspect oil heaters for proper oil temperature.
7.	Close burner air and/or stack dampers when the burner is off to minimize heat loss up the
8.	Improve oxygen trim control (e.g. -- limit excess air to less than 10% on clean

fuels), (5% reduction in excess air increases boiler efficiency by 1% or: 1% reduction of residual oxygen in stack gas increases boiler efficiency by 1%)
9. Automate/optimize boiler blowdown. Recover boiler blowdown heat.
10. Use boiler blowdown to help warm the back-up boiler.
11. Optimize deaerator venting.
12. Inspect door gaskets.
13. Insect for scale and sediment on the water side (A I mm thick scale (deposit) on the water side could increase fuel consumption by 5 to 8%.)
14. Inspect for soot, fly ash, and slag on the fire side (A 3 mm thick soot deposition on the heat transfer surface can cause an increase in fuel consumption to the tune of 2.5%)
15. Optimize boiler water treatment.
16. Add an economizer to preheat boiler feed water using exhaust heat.
17. Recycle steam condensate.
18. Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple boilers.
19. Consider multiple or modular boiler units instead of one or two large boilers.
20. Establish a boiler efficiency-maintenance program. Start with an energy audit and follow. up, then make a boiler efficiency-maintenance program a part of your continuous energy management program.

Steam System

21. Fix steam leaks and condensate leaks (A 3 mm diameter hole on a pipeline carrying 7 Kg/cm^2 steam would waste 33 Kilo liters of fuel oil per year)
22. Accumulate work orders for repair of steam leaks that can't be fixed during the heating season due to system shutdown requirements. Tag each such leak with a durable tag with a good description.
23. Use back pressure steam turbines to produce lower steam pressures.
24. Use more-efficient steam de-superheating methods.
25. Ensure process temperatures are correctly controlled.
26. Maintain lowest acceptable process steam pressures.
27. Reduce hot water wastage to drain.
28. Remove or blank off all redundant steam piping.
29. Ensure condensate is returned or re-used in the process. (6°C raise in feed water temperature by economizer condensate recovery corresponds to a 1% saving in fuel consumption in boiler)
30. Preheat boiler feed-water.
31. Recover boiler blowdown.
32. Check operation of steam traps
33. Remove air from indirect steam using equipment (0.23 mm thick air film offers the same resistance to heat transfer as a 330 mm thick copper wall)
34. Inspect steam traps regularly and repair malfunctioning traps promptly.
35. Consider recovery of vent steam (e.g. -- on large flash tanks)
36. Use waste steam for water heating.
37. Use an absorption chiller to condense exhaust steam before returning the condensate to the boiler.
38. Use electric pumps instead of steam ejectors when cost benefits permit.

39. Establish a steam efficiency-maintenance program. Start with an energy audit and follow-up, then make a steam efficiency-maintenance program a part o your continuous energy management program.

Furnaces

40. Check against infiltration of air: Use doors or air curtains.
41. Monitor O, /CO/CO and control excess air to the optimum level.
42. Improve burner design, combustion control and instrumentation.
43. Ensure that the furnace combustion chamber is under slight positive pressure.
44. Use ceramic fibers in the case of batch operations.
45. Match the load to the furnace capacity.
46. Retrofit with heat recovery device.
47. Investigate cycle times and reduce.
48. Provide temperature controllers.
49. Ensure that flame does not touch the stock.

Insulation

50. Repair damaged insulation (A bare steam pipe of 130 mm diameter and 100 m length, carrying saturated steam at 8 kg/cm^2 would waste 25,000 liters furnace oil in a year)
51. Insulate any hot or cold metal or insulation.
52. Replace wet insulation.
53. Use an infrared gun to check for cold wall areas during cold weather or hot wall areas during hot weather.
54. Ensure that all insulated surfaces are cladded with aluminum.
55. Insulate all flanges, valves and couplings.
56. Insulate open tanks (70% heat losses can be reduced by floating a layer of 45 mm diameter polypropylene (plastic) balls on the surface of 90°C hot liquid/condensate)

Waste heat recovery

57. Recover heat from flue gas, engine cooling water, engine exhaust, low pressure waste steam, drying oven exhaust, boiler blowdown, etc.
58. Recover heat from incinerator off-gas.
59. Use waste heat for fuel oil heating, boiler feed-water heating, outside air heating.
60. Use chiller waste heat to preheat hot water.
61. Use heat pumps.
62. Use absorption refrigeration.
63. Use thermal wheels, run-around systems, heat pipe systems, and air-to-air exchangers.

Electrical Load Management and Maximum Demand Control

1. Load Curve Generation
2. Rescheduling of Loads
3. Storage of Products/in process material/process utilities like refrigeration
4. Shedding of Non-Essential Loads
5. Operation of Captive Generation and Diesel Generation Sets
6. Reactive Power Compensation

Acknowledgement

I would like to express my deepest gratitude to the following esteemed members,

1. Randy Kerkstra – CTO at KB Molding Solutions, Michigan, USA
2. Steve Brammer – CEO at KB Molding Solutions, Michigan, USA
3. Dr. Cherry Bhargava – PhD in VLSI Design, Research Analyst, India
4. Dr. B. Koti Reddy – PhD in Power Systems,Department of Atomic Energy, India
5. Dr. Amit Kumar Singh – PhD in Electrical Engineering, Scotland, United Kingdom

Thank you.

Referrences

[1] Zhu T, Xiong P and Yu P S 2020 Future generation computer systems 108 1297. 306
[2] Amir M and Givargis T 2020 Internet of things 12 100308
[3] Kim J and Lee J Y 2021 Robotics and computer-integrated manufacturing 67 102040
[4] Sadek A, Hassan M and Attia M H 2020 CIRP Annals 69(1) 105-8
[5] Tehrani K 2020 Journal of systems architecture 111 101804
[6] Ramakrishna S, Karsai G and Dubey A 2020 Journal of systems architecture 111 101760
[7] Bokea J, Knaacka U and Hemmerlingb M 2020 Journal of building engineering 101397
[8] Wang D, Wang X, Zhang Y and Jin L 2019 Journal of information security and applications
[9] Khojasteh M J, Khina A, Franceschetti M and Javidi T 2019 IFAC 52(20) 369-74
[10] Gurjanov A V, Zakoldaev D A, Shukalov A V and Zharinov I O 2018 I0P Conference Series: Materials Science and Engineering 327(2) 022111
[11] Parto M, Saldana C and Kurfess T 2020 Procedia manufacturing 48 959-67
[12] Bozzelli J., Groleau R., and Ward N. "The Machine Audit: A Systematic Evaluation of Injection Molding Machines: How to Tell a Good Machine—Old or New" Antec 1993.
[13] Doyle K., "Know Your Machine", Plastics Technology, May 2014.
[14] Bozzelli J., "Know the Basics of Machine Evaluation, Part 1", Plastics Technology, 2010.

End Note