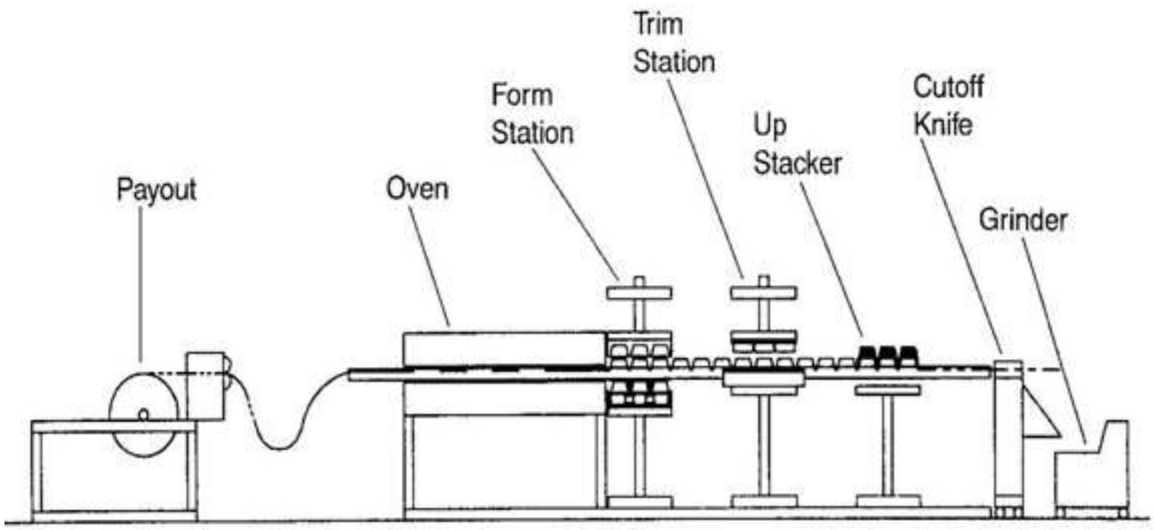
# In-Line Thermoforming with Steel Rule or Forged Steel Trim with Vacuum, Air Pressure and Plug Assist

This is a simplified drawing of an in-line thermoforming machine:




In-Line Process Overview
With this type of machinery, the forming and cutting are accomplished in a two separate dual platen stations. Achieving the desired geometry can be enhanced with the assistance of a mechanical plug assist. In the first station, if the mold is female in geometry, the mold is usually mounted to the upper platen and the mechanical plug assist is mounted to the lower platen. If the mold geometry is male, the mold is usually mounted to the lower platen and a grid assist is mounted to the upper platen. If steel rule or forged steel dies are used, the cutting die is usually mounted to the upper platen of the second station and the cutting plate is mounted to the lower platen. The process begins by indexing the sheet off the roll by means of pin chains mounted on rails that capture the sheet along its edges. The pin chain carries the captured sheet into the radiant heat tunnel oven. The surface of the plastic is heated, preferably from both sides, by various types of electric resistance radiant heat sources. CalRod, quartz panel, quartz tube, and other similar electric heaters are generally set up in zones to provide an adjustable heat profile to maximize caloric output and help manage energy costs. These radiant heaters should be adjusted so the wavelength of the heater output is in one of the infrared zone. This will maximize heat penetration of the sheet and provide for the shortest possible cycle time. Once the sheet is up to temperature, the machine indexes again and the sheet, held along its edges by the pin chains, is conveyed into the forming station. Some thermoforming machines are equipped with pin chain rails that are adjustable throughout the length of the section that transports the sheet into the forming station. The adjustable rails can be configured to accomplish a graduated stretch of heated plastic in the transverse direction as the machine indexes. This stretching is called camber, and it takes most if not all of the sag out of the heated sheet. There are several advantages to using camber including improved residual wall distribution, reduced edge trim scrap, and faster cycle times. The cycle time is reduced because of the reduced distance the

forming platens must travel. Once the heated plastic is to station, the upper and lower platens close, and the part is formed by the combined effects of mold and plug assist, and cooled by contact with the mold. The heat transfer from the part to the mold is enhanced by air pressure introduced through the pressure box that surrounds the mold or the plug assist. The machine indexes, bringing a new length or "shot" of heated sheet into the forming station. Simultaneously, the shot containing the formed parts is indexed into the cutting station. In the cutting station, the parts are cut from the web using steel rule or forged steel dies. When the process indexes the formed parts out of the cutting station, the parts are held in the web and transported to the next station by means of small conveyance notches. These tiny notches are filed or punched into the cutting edge of the die. The parts break free from the web when they are manually or mechanically stripped from the web and stacked for packing. The waste web is then conveyed to a coreless winder that rolls the web into bales, or it is fed directly into a grinder that converts it into flakes. In either case, this final station provides the pulling action needed to keep tension on the web, once the web has left the pin chains. If the scrap is ground, the resulting flake is usually blown or otherwise conveyed into a poly-bag lined corrugated gaylord container for recycling.

A simplified cut-in-place process description would look like this:

1. Plastic is pulled off the roll by a roll feed fixture at the front of the machine, just after the roll stand, and is fed into the pin chain rails where it is held by its edges, and indexed into the oven
2. In the oven the sheet is heated, preferably from both sides, until it reaches the desired temperature for thermoforming
3. The machine indexes and the heated plastic, still held by its edges on the pin chain, is carried into the forming station, and a new length of plastic is moved into the oven
4. Once the plastic is at station, the upper and lower platens move together. The heated plastic is formed by a combination of the mold and the plug assist, and the effect of vacuum and air pressure. Once the formed plastic is cool enough, the upper and lower platens open
5. The machine indexes and the formed parts, or "shot", is conveyed into the cutting station
6. Cutting is accomplished by the combined action of the upper and lower platens. Usually, the lower platen moves first, coming to within 95% to 98% of station. Then the upper platen with the die moves to 100% station. Once the upper platen is at station, lower platen is then "bumped to 100% station by air or hydraulic cylinders, and the cut is accomplished
7. The machine indexes and the cut parts, still held in the web by the conveyance notches, leaves the pin chains and moves to the manual and/or mechanical stripping and stacking station
8. The parts are stripped from the web, and then stacked and packed in containers for shipping
9. The machine indexes and the waste web is either wound into a coreless bale, or pulled into a grinder for recycling

## Advantages

The in-line thermoforming process is used to form almost every type of plastic used in the packaging industry. It is extremely versatile and may be modified and configured in many ways and is the ideal general-purpose thermoforming machine. New projects can be prototyped quickly and inexpensively. In addition, more than one type of part geometry can be formed and trimmed in each shot. This combination of geometries is referred to as a combo-run or combo-shot. The net effect is that it is possible to form the separate components needed for a complete assembly every time the machine cycles. Finally, the cost of this type of thermoforming machine, while generally more than contact heat machines, is usually significantly less than two-station, matched metal technology.

## Disadvantages

The principal disadvantage is because the forming and cutting processes are inseparable and are slaved to the same tangent of motion. While this simplifies the operation of the machine, it limits the finishing options available to the part designer. There are also limitations in the ability to control the distance of platen travel, and this extra motion adds waste to the cycle. The slaved design of the forming and trim stations can also limit the amount of force available for trimming the part. While steel rule and forged steel dies are excellent ways to trim plastic parts, the closest tolerance trimming is accomplished utilizing a punch and die assembly often referred to as matched metal trimming. The clearance needed by the matched metal tool virtually eliminates it a trimming process available to the part designer.

## Thermoforming and Cutting Troubleshooting Guide

1. Forming Defects
2. Poor Detail
    1. Material is too cold
        1. Check oven temperature
        2. Check heat time
        3. Raise coolant temp control or restrict flow to raise mold temp
    2. Form Pressure too low
        1. Check seals and vents
        2. Check hoses for leaks
        3. Be sure compressor and vacuum pump are functioning
    3. Plastic is too hot
        1. The plastic is cloudy due to overheating. The cloudy condition is caused by heat induced crystallinity
        2. Cycle the machine faster or lower heater set points
    4. Plastic has been heated too long
        1. Time and temperatures under 190 degrees Fahrenheit will induce crystallinity that is transparent and will make the sheet very stiff
        2. Be sure all heating elements are functioning
        3. Increase heater outputs
        4. Be sure heaters are set to radiate in the infrared wavelength
        5. Shorten the machine cycle time

    5. Inadequate seal in tool or sheet clamp
        1. Check hoses and seals for leaks
        2. Vacuum hole may be plugged
            1. Clean mold and clear vents
            2. Probe vents after texturing to clear obstructions
    6. Sheet over gauge
3. Too Much or unwanted Detail
    1. Vent holes too large
    2. Plastic is under gauge
    3. Air Pressure too high
4. Webbing or bridging
    1. Material is stalling instead of flowing
        1. Plastic or mold surface may be too cold
    2. Adjust timing of forming
    3. Adjust vacuum timing
    4. Be sure vacuum is adequate and effective
    5. Adjust Air pressure timing
    6. Platen speed too fast
    7. Failure in temperature control system
    8. Blown fuse to thermocouple or controller, bad wire
    9. Index length too short
    10. Adjustment in zone heating profile needed
    11. Thin spot in the plastic
    12. Perimeter sheet clamp failure
5. Distorted geometry or warped parts
    1. Cooling time too short
        1. Part coming off mold too hot
    2. Surface temp of mold too warm
        1. Increase coolant efficiency through turbulence inducing inserts
        2. Be sure water circulating pump is running
        3. Check for kinked hoses
        4. Check for blockage in mold cooling ports
    3. Insufficient cooling to the mold
        1. Heat transfer inefficient between mold and cooling plate
            1. Consider improving efficiency by redesigning and eliminating the cooling plate
            2. Water circulating pump has not kicked off
    4. Part is hanging up on mold during ejection
        1. Scrapes and wrinkles are observed
    5. Air pressure too low
        1. Check to be sure air eject ports in mold are not plugged
        2. Make sure hoses are not kinked or cut
        3. Check status of compressor
6. Dents or wrinkles in parts
    1. Part is sticking to the mold
        1. Mold surface may need maintenance

    2. Platens opening too fast
    3. Air eject ports may be obstructed
    4. Timing adjustment in air eject cycle needed
    5. Air eject pressure too high
        1. Bottom of part is caved in or wrinkled
    6. Inadequate clearance for parts in trim die relief or stacker
    7. Chain rails out of synchronization side-to-side or out of parallel
    8. Sheet advancing before parts clear the mold
    9. Parts hit an obstruction during conveyance
    10. Stacker needs adjustment
7. Poor material distribution
    1. Adjust mold temperature
        1. Mold surface usually too cool
        2. Surface temp of mold inconsistent
    2. Adjust form air timing
    3. Adjust vacuum timing
    4. Adjust platen speed
    5. Thickness of plastic out of specification
    6. Sheet temperature inconsistent
        1. Check heat zone temps
        2. Adjust heat zone profile
    7. Plug geometry or plug timing needs adjustment
        1. Increase plug radii
        2. Eliminate sharp corners
        3. Adjust depth of plug travel
        4. Adjust plug speed
        5. Plug may need texturing
        6. Be sure plug is not too fat
    8. Plug material is non-insulative
        1. Plugs should not remove heat from the sheet
8. Plug Marks
    1. Realign plugs in cavity
    2. Plug mounting screws are loose
    3. Plug geometry needs streamlining
    4. Plug depth-of-travel needs adjustment
    5. Plug material is non-insulative
    6. Plug is too fat
9. Thin spots in Parts
    1. Adjust sheet temperature
    2. Plug is too fat
10. Surface of Parts is dimpled
    1. Adjust mold temperature
    2. Mold surface needs maintenance
    3. Air Trapped between sheet and flat mold surface
        1. Add vent holes to flat surface
        2. Clear existing vent holes

        3. Enlarge existing vent holes
    4. too much release agent on sheet
11. Chill Spots
    1. Water leaking out of mold
    2. Water channel blocked in cooling plate
    3. Sheet touching metal surfaces during index
    4. Mold too cold
        1. Condensation dripping on mold surfaces
    5. Plug material non-insulative
    6. Air draft cooling area of sheet
        1. Be sure fans are not blowing toward forming station
        2. Check hoses for air blowing on the sheet while indexing
12. Hot Spots
    1. Be sure vacuum is turned on
        1. Check all valves and breakers
    2. Check for loss of vacuum due to leaks in mold
        1. use good cigar or canned smoke, talcum powder or corn starch to find leaks
    3. Mold surface may need maintenance
    4. Adjust timing of form air
    5. Adjust timing of vacuum cycle
13. Inconsistent forming process
    1. Oven operation is impaired
        1. Be sure the oven is adequately pre-heated
    2. Drafts are effecting even heating in oven
    3. Heater elements operating inconsistently
        1. Check wiring and other power connections
        2. Heaters may be dirty, corroded, or worn out
    4. Check unwind stand and sheet feed system
        1. Sheet may not feeding off roll smoothly
        2. Sheet may be binding in duck bill
        3. Pin chain is slipping
            1. check for sheared pins in sprockets
    5. Sheet clamps are ineffective
    6. Mechanical sheet clamps are worn out
    7. Seal on pressure box has failed
        1. Be sure pressure box is holding pressure during the cycle
14. Blowing Holes
    1. Air eject pressure too high
    2. Air trapped in cavity
        1. Plug is too fat
        2. “Dog bone” plug
        3. Flute sides of plug
        4. Larger radii needed on leading edges of plug
        5. Plug surface needs attention
        6. Bring vacuum on earlier in cycle

        7. Decrease plug speed
    3. Plug does not reach material early enough
    4. Material is freezing to non-insulative plug material
    5. Plug surface is too rough
15. Thick bottom
    1. Decrease plug speed
    2. Bring vacuum on sooner
    3. Increase size of radii on plug
    4. Plug is made from a non insulative material
    5. Be sure vacuum bleed valve is functioning
16. Thin Bottom
    1. Increase plug depth
    2. Increase plug speed
    3. “Dog bone” plug
    4. Generalize the plug geometry
    5. Be sure vacuum bleed valve is functioning
    6. Check forming air pressure timing

1. Trimming Defects
2. Location of trim is not centered
    1. Adjust or repair die
3. Angel Hair, chaff and fuzz
    1. Check die sharpness
    2. Cut against a hardened plate
    3. Cut lines in trim plate
    4. Be sure there are no burrs on cutting edge
    5. Check backer plates for flatness
    6. Check platens for parallelism
    7. Check conveyance and stacking fixture clearances
4. Feathered edges
    1. Check die sharpness
    2. Cut against a hardened plate
    3. Cut lines in trim plate
    4. Be sure there are no burrs on cutting edge
    5. Check backer plates for flatness
    6. Check platens for parallelism
    7. Conveyance notches too big

1. Surface Defects
2. Check area for sources of airborne particles
    1. Check for open doors, windows, cleaning, fork truck traffic
    2. Remove dirt and debris from under and around machine
3. Mold surfaces may need maintenance
4. Clear chads, punch-outs, and plastic debris from forming and cutting area

5. Adjust mold temperature
    1. Water leaking out of mold
    2. Water channel blocked in cooling plate
    3. Sheet touching metal surfaces during index
    4. Mold too cold
        1. Condensation dripping on mold surfaces
6. Plug material non-insulative
7. Air draft cooling area of sheet
        1. Be sure fans are not blowing toward forming station
        2. Check hoses for air blowing on the sheet while indexing
8. Air Trapped between sheet and flat mold surface
    1. Add vent holes to flat surface
    2. Clear existing vent holes
    3. Enlarge existing vent holes
9. Too much release agent on sheet
10. Check sheet and pallets it came on for dirt or debris
11. Check sheet for air bubbles, black specks, pits and gels