For many converting operations, a flotation drying system represents the longest web span between tension isolation points on the entire coating line. As such, web stability inside the dryer can be a concern. Current trends toward faster line speeds and lighter weight substrates only serve to compound dryer web-handling challenges. Problems such as troughs, edge flutter, edge curl, web-weave and web shift are often attributable to dryer design or operation. This paper will explore the various conditions that can create or contribute to such web-handling problems. In addition to web handling, we will also address common dryer-related coating defects such as blistering, pinholes, orange peel effect, and cratering. The author will discuss appropriate test methodology for identifying the root cause or causes of web handling problems and dryer-induced coating defects, and will offer options for corrective action and process quality enhancement.

Unique Challenges of Flotation Dryer Technology

When it comes to web handling, flotation drying presents a number of inherent challenges that are unique to the technology. Unlike roll support equipment where the heat transfer and web handling components of the drying process are independent (i.e. web handling via idler rolls and heat transfer via impingement air distribution nozzles or other forms of heat distribution), flotation dryers combine these process components into the functional design of the flotation nozzles or air-bars (Fig 1). Given this fact, air-handling uniformity is far more critical to the web-handling performance of a flotation dryer than it is with roll support technology. Therefore, a full understanding of the dryer air-handling systems, nozzle design, and the balance between heat transfer and web handling, are critical to the process of troubleshooting flotation drying problems.

Fig 1. Unlike roll support systems, flotation nozzles provide both heat transfer and web support functions.
Before we can review the specific web-handling challenges associated with flotation drying, it is necessary to define “good web handling performance” as it relates to this technology. In general, good web handling in a flotation dryer is understood to mean a stable, non-fluttering, non-wrinkling, uniform nozzle to web clearance. In other words, no nozzle contact with the web or coatings and no “out-of-plane” web movement that could contribute to coating defects or web control issues.

To insure adequate nozzle to web clearance, there must be a balance maintained between web tension and nozzle air velocity as can be seen in (Fig 2) below. Of course, the exact window of operation will vary depending upon several factors including; the type of substrate, the thickness and density of the substrate, material characteristics such as extensibility and porosity, the properties of the coatings, the geometry of the nozzle design, the pressure and flow capabilities of the dryer air handling system, and the design and capabilities of the process tension control system. Since the flotation principles are dependent upon both tension and velocity, it should be noted that the flotation dryer itself must be a controlled tension zone.

Typical Web-Handling Challenges

Due to the complex nature of the topic, we will examine only the most common web-handling challenges that can arise within a flotation drying process. For each challenge, we will attempt to define the problem, discuss potential root cause/s, identify appropriate troubleshooting methodology and finally, recommend corrective action.

Web Troughs and Wrinkling

Troughs are machine direction waves or undulations that are usually caused by compressive forces in the web resulting from tension. Troughs can be thought of as precursors to “wrinkles” in so far as wrinkles are a hard crease or “fold-over” of web material that starts as one or more troughs that eventually bunch up and fold over. This creasing usually takes place when a trough passes over a roller or through a nip downstream of the drying process.
If web troughs are visible within the dryer, operators should focus their troubleshooting efforts on rebalancing the nozzle velocity and dryer tension. Reducing the tension and/or increasing air velocity slightly will usually remove or minimize the troughs. In some cases, non-uniform caliper or gauge bands in the substrate contribute to the formation of troughs. In these cases where tension adjustments do not fully prevent troughs from forming, bowed rolls or spreader rolls may be helpful in removing web troughs and wrinkles downstream of the dryer.

Web Flutter

Perhaps one of the most common problems associated with flotation drying is the potential for web fluttering. Web flutter can be defined as “out-of-plane” motion, typically at the edges of the web, but sometimes, over the entire web width (as in a billowing sail). If the fluttering is extreme enough, it could result in nozzle touchdowns and/or coating defects created by the substrate oscillation.

Web flutter can be caused by any number of, process, substrate, or dryer design related issues. Some of the contributing causes are: bad nozzle alignment, poor nozzle design, poor exhaust system design, inappropriate air bar to air bar separation, baggy edged webs, material deformation in extensible webs, substrate gauge bands, web thickness non-uniformity and tension.

In a flotation dryer, high tension relative to nozzle velocity is more often than not at the heart of the problem. Small adjustments of both nozzle supply pressure and line tension almost always reduce or eliminate the flutter. For heat sensitive webs like polypropylene or polyethylene, operators may need to experiment with air temperature as well to further alleviate the flutter.

If fluttering persists after attempts to adjust the tension/velocity relationship via damper repositioning, fan drive speed changes or tension zone set point changes, then the dryer needs to be checked for uniform nozzle gap width, and nozzle-to-web distance. A common misconception is that increasing the distance from nozzle to nozzle across the web will reduce flutter (and touch downs resulting from same). Although it may seem somewhat counter-intuitive, exactly the opposite is true.

To check for cross-machine nozzle velocity uniformity, use a manometer and a pitot tube fastened to an extension rod. A measurement of +/- 2% uniformity is considered to be excellent, +/- 5% is fair to good and +/- 10% poor to unacceptable. Check slot nozzle uniformity using a taper gauge. Non-uniform slots can result in uneven air pressure across the web that in turn, could result in web flutter. Poor nozzle/header alignment can also contribute to flutter. To check alignment, you can pull a taut wire through the dryer on both the operator and gear side at the web height and measure the distance.
between the wire and nozzle with a taper gauge.

**Web Shift and Web Weave**

Web shift is the movement of the web to a relatively steady position away from its centerline, either to the operator or gear-side of the machine. Web shifts most often occur when new rolls are spliced or when processing conditions are altered (coat weight thicknesses, tension, drive gains, nip pressures etc.)

Web-weave, on the other hand is a cyclic, back and forth movement corresponding to periods of oscillation in line tension or tension profile in the cross-machine direction. Under constant airflow conditions, a flotation dryer will not cause web weave. Rather, the dryer will simply react to the varying cross-machine tension.

It is virtually impossible to discuss the subject of web shift or weave without first acknowledging the impact of web camber on flotation dryer performance. Even if the dryer is in perfect alignment and airflow/velocity is uniform across the web, lateral forces on the web will still result from a “cambered” web (Fig 3). In addition to camber, it should be noted that other machine conditions such as misaligned rollers, cross machine variations in nip pressures or other upset conditions resulting in non-uniform, cross-machine web tension also contribute to web shift and weave.

(Fig 4) shows a web that exhibits camber when rolled out flat. Other substrate non-uniformities such as baggy edges and variations in cross-machine caliper can cause similar web tracking behavior. When pulled straight between two points, a cambered web will have higher tension on the short radius side and lower tension on the long radius side. Bearing in mind that tension readouts on machine lines indicate “average” tension, it is possible to see significant variations in actual tension from one side of the web to the other.

If the cambered web in our example is placed under sine wave flotation forces inside a dryer, a lateral force is created due to the difference in flotation height in the cross-machine direction (Fig 5 below). This lateral
force steers the web away from the low-tension side of the web.

If you are experiencing web shift in your flotation dryer, troubleshooting should begin with a check for substrate uniformity. The best way to do this is to roll out a length of web onto the floor (20 times the web width is usually plenty of material) and then measure and record the camber using a taut nylon fishing line and tape measure.

To determine the actual impact of camber inside the dryer, it can be very helpful to run your cambered roll noting the direction and amplitude of the shift. Then flip the roll over and run it again. If the web shifts to the opposite side of the machine, then camber is very likely the main contributor to the shifting problem. If web camber is the issue, operating under slightly higher than normal tension may help somewhat. However, this practice could induce other problems such as troughs, wrinkles or web flutter. Normally, a steering guide at the dryer exit will be more than adequate to redirect a cambered the web to the machine centerline for downstream slitting or rewinding (Fig. 6).

On the other hand, if the web is flipped over but continues to shift to the same side of the machine as before, then other factors such as poor nozzle alignment, non-uniform supply-air velocity, poor cross-machine handling of spent air, misaligned rollers, or non-uniform nip pressure must be considered.

If you suspect that the dryer itself may be causing the shift, check the nozzles for cross-machine airflow uniformity, nozzle gap width and nozzle alignment using the same methods mentioned above in the section on web flutter.

For web weave issues, check for poorly set up and/or improperly tuned web guides, or any indications of loss of roll traction (especially at the steering rolls). Loss of roll traction can be the result of surface finish issues, surface contamination or simply the air layer that can form between the rolls and the web when operating at fast line speeds. Cross-machine tension variation can also be caused by unbalanced air pressure at nip points, in vacuum rolls or other gripper type rolls or belts. If roll traction and nip/vacuum pressures are relatively constant, an
overactive or badly tuned web
guide/steering roll can also be the root cause of web weave.

Common Dryer-Related Coating Defects

There are no drying process-induced coating defects that are exclusive to flotation style dryers. However, the process of troubleshooting and correcting coating defects in flotation dryers differs from roll support equipment due to the dual-functionality of the nozzle design in flotation dryers.

Blistering

Blistering is a phenomenon caused by “boiling” under the surface of the coating layer that results in bubbles that may or may not burst at the surface (Fig. 7).

Blisters are normally the result of excessive evaporation rates and can be controlled by reducing heat transfer in the early phase of drying. Blisters are formed when the surface of the coating “skins over” trapping solvent vapors beneath the surface. Drying process adjustments that will slow evaporation and minimize skinning include reducing air temperature, reducing impingement air velocity and if possible, adding heat from the bottom-side only. If these adjustments do not eliminate the defect, there may be no alternative but to slow down production or reformulate the coating.

Orange Peel Effect (Convection Cells)

Orange peel effect (Fig 8) is a puckering of the coating surface caused by density or temperature gradients across the web or within the coating. If the dryer is causing the defect, reduce drying air temperatures, especially in the early zones of a multi-zone dryer.

Drying Mottle

Mottle (Fig.9 can be described as a non-uniform surface disturbance or pattern (usually only observable under magnification) that is caused by non-uniform air distribution to the web. In severe cases, these disturbances are visible to the naked eye as areas where the coating looks to have been “blown around” by the air.
If mottling occurs, you will want to verify the dryer cross-machine airflow, velocity and temperature uniformity using the techniques previously described.

Dryer Bands

Dryer bands, as the name implies, are continuous, machine direction disturbances in the coating, visible as parallel lines across the web that correspond directly with airflow emanating from rows of holes or circular nozzles above the coating. Sometimes a non-uniform slot nozzle will create isolated dryer bands that correspond to variations in slot width across the web. As far as traditional “coanda style” nozzle designs are concerned, more often than not, reducing impingement velocity along with tension will eliminate this defect. If this doesn’t work, you may need to back the nozzles away from the web in addition to reducing the impingement velocity.

Non-traditional flotation nozzle designs that use hole bars or circular jets to impinge on the web are more likely to create dryer bands. These types of nozzles may need physical modification to fully eliminate the defect.

Pin Holes

Although often attributed to the drying process, pinholes (Fig 10) are generally caused by contamination (air bubbles or particulate in the coating itself or oil, grease or other contamination on the substrate). Filtering of the coating and the use of additives to reduce foaming will often eliminate the defect. Also, fluid mixers and pumping systems may need cleaning or repairs to limit introduction of contaminants and air bubbles.

Cratering

Like pinholes, craters (Fig. 11) are not actually a dryer related phenomenon. Craters are normally caused by uneven wetting of the coating due to variability in surface tension of the substrate. It could be the result of substrate contamination from oils or silicones but cratering is often the result of non-uniform deposition of release coatings.
Curling and Cracking

Curling and cracking (Fig 12) are related defects caused by the build up of unequal stresses in the coating and substrate as they move through the dryer. As the coating dries, its volume is reduced and the resulting shrinkage either curls the web toward the coated side or forms cracks in the coating itself. In the case of paper or board substrates, uneven moisture loss from one side of the base substrate (i.e. coated vs. uncoated side) can result in curl due to fiber shrinkage.

Edge curl is actually minimized in flotation style dryers since the sine wave adds strength to the web profile and retards the formation of the curls. If curling does occur in a floater, the operator may need to increase both the supply air velocity and the flotation clearance between the web and nozzles in order to prevent touchdowns or scraping of the outside edges of the web. If curl presents a problem after drying, reduce drying temperatures to the greatest extent possible while meeting requirements for solvent removal, i.e. do not over dry.

Blushing

Blushing is a milky, opalescence of the coating caused by the surface temperature of the coating falling below the dew point of the air. In other words it is created by condensation of solvent vapor and water on the coated surface. Simply increasing the air temperature will normally prevent this defect.

Scratching

Scratching (Fig 13) appears as machine direction grooves or striations in the coating that appear in the same position across the web. Physical contact with the nozzles or web slots is typically responsible for this defect. The most likely cause of touchdowns is some upset of the tension/velocity relationship within the drying process.

Scuff and Dig Marks

Fig. 11. Crater resulting from non-uniform release coating deposition.

Fig 12. Edge curl resulting from shrinkage of the coating as it dries.

Fig. 13. Scuffs and scratches can occur when tension and nozzle velocity are out of balance.
When troubleshooting, check line tension set points and supply air velocity set points to insure proper flotation clearance between the nozzles and web. Misaligned nozzles can also cause physical contact and should be checked as well.

As for web slot contact, check the entrance and exit rolls for alignment first. If the problem persists, you may need to make minor adjustments to the impingement angle of the first nozzles inside the dryer at either end of the device. Sometimes the first nozzle inside of a flotation dryer is dampered to allow for varying the impingement velocity to insure non-contact as the web transitions from rolls to air flotation.

Summary

In order to successfully troubleshoot web handling, and/or coating defects inside flotation dryers, machine operators must develop a reasonably good understanding of air flotation theory, air bar design, and the tension/velocity relationship that plays such an important role in dryer performance. Most common web handling problems such as web flutter, troughs and wrinkling and coating defects such as curling, cracking, blushing and scratching, can be resolved with minor adjustments in tension, supply air velocity and air temperature. In addition to these control variables, coating defects such as blistering may require physical reconfiguration of the nozzles and/or line speed reductions to fully correct the problems. Finally, some web handling challenges such as web shift, and web weave will normally require web guides or steering rolls at the dryer exit to insure accurate downstream web processing.

Acknowledgements:

1. Coating defect photos courtesy of AIMCAL. Photos extracted from the AIMCAL Defect Lexicon.

2. Coating defect definitions are based upon the definitions contained in the following publication:

"Modern Coating and Drying Technology"
by Edward D. Cohen and Edgar B. Gutoff