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BATCH TUNNEL WASHING

ISO 9001:2015 CERTIFIED
(Quality Management System)

Table of Contents

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Overview

The purpose of this publication is to familiarize you with the science behind batch tunnel washing systems, specifically Braun Batch Tunnel Washers (BTW). This includes the mechanical operation and features, process flow and control, chemistry, time, sizing and throughput considerations; as well as the wide range of goods classifications that can be processed.

Machine Operation and Process Flow 2
Machine Features 4
Cylinder 4
Seals 4
Drive System 5
Chemical Injection 5
Rapid Drains 6
Heating System 6
Water and Heat Recovery 7
Transfer Method and Wash Process 9
Counterflow 10
Bath Exchanges 11
Wash Pie 12
Chemical Profile 13
Mechanical Action 14
Wash Testing Results 16
Applications 17
Sizing 17
Overall System and Processing Considerations 19
Goods Processing Flexibility 21
Summary 22
Tunnel System Extraction Methods 23
Fundamentals of Drying and The Dry Pie℠ 25-35
Temperature 26
Airflow 28
Mechanical Action 30
Time 32
Heat Recovery 35-36
Lint Collection 37
Preventative Maintenance 38-39
Dryer Types 40
Dryer Types and Material Handling 41
Dryer Unloading Options 42
Appendix 43

Machine Features

Braun Batch Tunnel Washers are designed to provide users with an efficient processing solution that is easy to operate and simple to maintain. This is accomplished by a robust heating and energy recovery system as well as a mechanical design philosophy centered on reliability, durability and simplicity.

The batch tunnel washer has three classifications available, 130 and 150 pound classifications and a 220 pound classification **(These weights are based on the clean dry weight of linen, not soil weight).** The 130 weight classification has three compartment configurations, 10, 13 and 16 compartment. The 150 and 220 weight classifications have configurations of 8, 11 and 14 compartment configurations.

A model of the 150 BTW-11 is shown in **Figure 1** as an example of the tunnel washer.

Figure 1—150 BTW-11 model

Each Braun BTW has five zones: prewash, wash, post wash bath exchange, rinse, and finish. The different compartment sizes will offer the same general functionality, with slight differences in the function of each chamber. The following defines the functionality and features that are common to each zone:

Zone 1: Prewash zone

- Function is to provide initial wetting of goods, application of heat and chemistry early in the process, and to remove as much soil as possible from goods prior to entering the wash zone
- Process water to feed the prewash zone is from the wetout tank
- Reclaimed wetout tank process water is made up of reclaimed rinse and press water
- Drains from the prewash zone are to the floor or to an installed heat and waste water reclamation system

Zone 2: Wash zone

- Function is to provide application of heat, chemistry and mechanical action to thoroughly remove any remaining soil from goods after the prewash section
- Process water fed to the wash zone is from the rinse reclaim tank. It is fed continuously to the last wash chamber and counterflows to the wash drain
- Rinse reclaim tank process water is made up of reclaimed rinse water, press hydraulic cooling water, and post wash bath exchange reclaimed water
- The main wash zone can be drained to the floor or to an installed heat and waste water reclamation system

Zone 3: Post wash bath exchange zone

- Function is to provide rapid removal of spent wash process water, coupled with refill volume using finish water, to aggressively initiate the rinsing operation
- Process water is drained from the post wash bath exchange to the rinse reclaim tank
- Bath exchange is refilled from the final rinse reclaim tank
- Final rinse reclaim process water is made up of reclaimed post rinse bath exchange water
- There are no drains to the floor in this zone

Zone 4: Rinse zone

- Function is to remove all residual alkali, detergent, and/or bleach from the goods after the wash process
- Process water fed to the rinse zone is a combination of fresh and press reclaim water, it is fed to the last rinse zone and counterflows to the first rinse zone
- The main rinse drain is drained to the rinse reclaim tank
- There are no drains to the floor in this zone

Zone 5: Finish zone

- Primary function is to neutralize residual wash chemistry using sour and antichlor (for chlorinated bleach applications); additionally, softener is applied in this zone and if desired starch can be also applied
- Process water is drained from the finish bath exchange to the final rinse reclaim tank
- Process water fed to the finish zone is a combination of fresh and press reclaim water used for bath exchange refill and finish zone level control
- There are no drains to the floor in this zone

To define the operations for each chamber, a waterway functionality matrix is used to map all of the transfer, injection, and heating processes. Waterways are discussed later in this technical bulletin in more detail. They provide a means for the transferring of fluids, steam and chemicals to the internal areas of the BTW cylinder. This allows the Braun BTW to avoid the use of a maintenance intensive external "double drum" design. These charts are shown in **Table 1** for each compartment configuration.

BTW-8 Waterway Functionality Matrix

Chamber	# Waterways	Drain	Drain Type	Process Fluid In	Fluid Type	Spade Type	Heat In	Chemical injection Capable	Chemicals Injected
1	1	Yes	Programmable Rapid drain #1	Yes	Programmable Bath exchange #1 refill	Process feed to chute; chemical ports on chute; Blank on waterway	S1 S2	Yes	Alkali, Detergent
2	1	Yes	Wash drain	No		Blank		No	
3	1	No		No		Chemical	S4	Yes	Alkali, Detergent, Peroxide
4	1	No		Yes	Wash flow	Chemical/ Water	S9	Yes	Alkali, Detergent, Peroxide
5	1	Yes	Programmable Rapid drain #2	Yes	Programmable Bath exchange #2 refill	Chemical/ Water	S8	Yes	Alternate Bleach
6	1	Yes	Rinse drain	No		Chemical		Yes	Alternate Bleach
7	1	No		Yes	Rinse flow, press reclaim makeup	Chemical/ Water		Yes	Bleach
8	1	No		Yes	Fresh water, press reclaim makeup	Chemical/ Water	S7	Yes	Sour, antichlor, softener

BTW-11 Waterway Functionality Matrix

Chamber	# Waterways	Drain	Drain Type	Process Fluid In	Fluid Type	Spade Type	Heat In	Chemical injection Capable	Chemicals Injected
1	1	Yes	Programmable Rapid drain #1	Yes	Programmable Wetout feed Bath exchange #1 refill	Process feed to chute; chemical ports on chute; Blank on waterway	S1 S2	Yes	Alkali, Detergent
2	1	Yes	Programmable Rapid drain #2	Yes	Programmable Bath exchange #2 refill	Chemical/ Water	S3	Yes	Alkali, Detergent
3	1	Yes	Wash drain	No		Blank		No	
4	1	No		No		Chemical	S4	Yes	Alkali, Detergent, Peroxide
5	1	No		No		Chemical	S5	Yes	Alkali, Detergent, Peroxide
6	1	No		Yes	Wash flow	Water	S9	No	
7	1	Yes	Programmable Rapid drain #3	Yes	Programmable Bath exchange #3 refill	Chemical/ Water	S8	Yes	Alternate Bleach
8	1	Yes	Rinse drain	No		Chemical/ Water		Yes	Alternate Bleach
9	1	No		Yes	Rinse feed/ press reclaim alternate rinse feed	Chemical/ Water		Yes	Alternate bleach
10	1	Yes	Programmable Rapid drain #4	Yes	Programmable Bath exchange #4 refill	Chemical/ Water		Yes	Sour, Antichlor, softener, starch
11	1	No		Yes	Press reclaim	Chemical/ Water	S7	Yes	Starch

BTW-14 Waterway Functionality Matrix

Chamber	# Waterways	Drain	Drain Type	Process Fluid In	Fluid Type	Spade Type	Heat In	Chemical injection Capable	Chemicals Injected
1	1	Yes	Programmable Rapid drain #1	Yes	Programmable Wetout feed Bath exchange #1 refill	Process Feed to chute; chemical posts on chute; Blank on waterway	S1 (tank) S2	Yes	Alkali Detergent
2	1	Yes	Programmable Rapid drain #2	Yes	Programmable Bath exchange #2 refill	Chemical/ Water	S3	Yes	Alkali Detergent
3	1	Yes	Wash drain	No		Blank		No	
4	1	No		No		Chemical	S4	Yes	Alkali Detergent Peroxide
5	1	No		No		Chemical	S5	Yes	Alkali Detergent Peroxide
6	1	No		No		Blank	S6	No	
7	1	No		Yes	Wash feed	Chemical/ Water	S9	Yes	Alkali/Detergent
8	1	Yes	Programmable Rapid drain #3	Yes	Programmable Bath exchange #3 refill	Chemical/ Water	S8	Yes	Alternate Bleach
9	1	Yes	Rinse drain	No		Chemical		Yes	Alternate bleach
10	1	No		Yes	Alternate rinse feed Press reclaim	Chemical/ Water		Yes	Bleach
11	1	No		Yes	Rinse feed	Chemical/ Water		No	Bleach
12	1	Yes	Programmable Rapid drain #4	Yes	Programmable Bath exchange #4 refill	Chemical/ Water		Yes	Sour
									Antichlor
									Softener
13	1	No		Yes	Press reclaim	Chemical/ Water	S7	Yes	Finish-starch
14	0	No		No				No	Finish dwell only

Table 1—Waterway matrices

Legend for BTW zone identification:

Prewash	
Wash	
Post Wash Bath Exchange	
Rinse	
Finish	

Steam Zone Designations	
S1	Wetout tank steam
S2	Wetout feed line steam
S3	Bath exchange #2 feed line steam
S4	Wash zone sparge steam
S5	Wash zone sparge steam
S6	Wash zone sparge steam
S7	Finish zone sparge steam
S8	Final rinse reclaim tank steam
S9	Wash zone feed line steam

Cylinder

There are two prevailing designs for the cylinder of a Batch Tunnel Washer. These are referred to as single drum and double drum. Some Batch Tunnel Washers have portions of their cylinder that are single drum and portions that are double drum. This is referred to as combination drum. Single drum cylinders are a single, solid weldment with external waterways and seals. Double drum cylinders are essentially a tube within a tube. The internal tube is perforated to allow water to flow in and out. The external tube is stationary without perforations and is a means for water and chemical input. Each design has advantages and drawbacks. See **Appendix 1** for a more direct comparison of the two designs.

The Braun BTW is a single drum design. The cylinder is a solid weldment constructed of 10 gauge 304 stainless steel. This simple and rugged design is the backbone of the machine. The internal members are precisely designed to provide optimum washing and transfer capability.

Figure 2—BTW cylinder (11 Chamber)

The cylinder chamber sizing is based on the ability to contain a load both statically (cylinder stopped) and dynamically (during oscillation). While the cylinder is stationary 40% of the volume of the cylinder is used to contain the goods and keep chamber isolation. While the cylinder is oscillating, 70% of the volume of the cylinder is used for the same purpose. This can be seen in **Figure 3,** which identifies the cylinder use from both a static and dynamic perspective.

During transport, the entire cylinder volume is used to move the contents of one chamber to the next chamber, keeping the contents separate from all other chambers.

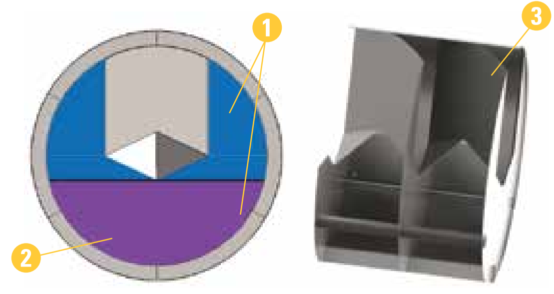


Figure 3—model of static/dynamic chamber volume

1. Dynamic Volume (blue & purple area)
2. Static Volume (purple area)
3. Open area for transfer

Seals

The type of seals used on a tunnel washer is dependant on the cylinder design. With a single drum design, all seals are external and easily accessible. Seals on a double drum cylinder are between the two drums, which make access and functional visibility very difficult.

Due to its single drum design, all seals on the Braun BTW are external to the machine. The seals provide a water tight barrier for the perforated waterways of each chamber. All water, chemical, and steam injections, as well as drains, are accomplished via affecting a small opening in the seal at the desired location and chamber for the transfer of aqueous material. The seals are made of an engineered polymer that is suitable for hot water, chemical, and steam contact.

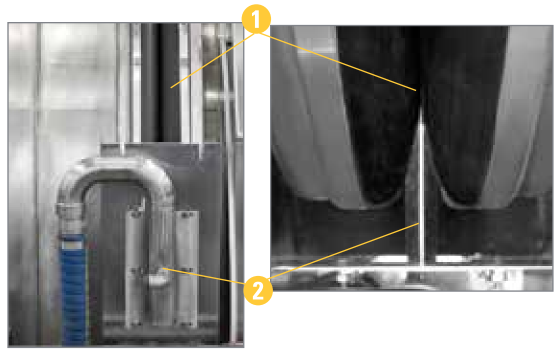


Figure 4—Tunnel seals

1. Seals
2. Injection Spade

Drive System

The Braun BTW is powered by a simple, rugged friction drive system. It consists of four drives that act on the two cylinder drive rings. Each drive has a three sprocket setup, which is composed of a gear motor driving two pairs of drive wheels through a carbon fiber belt. The gear motors are controlled with individual variable frequency drives (inverter) that precisely control the rotation of the machine during the washing and transport process. All bearings used in the drive system are sealed spherical roller bearings. The structure of the drives is provided by ductile iron castings.

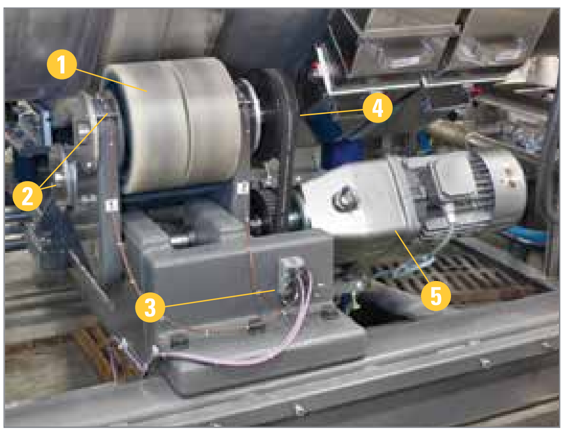


Figure 5—Drive System

1. Drive Wheels
2. Sealed Spherical Roller Bearings
3. Thermocouples
4. Belt/Sprockets
5. Gearmotor

The Braun BTW can operate if one gearmotor fails. This allows plant operations to unload the machine prior to maintenance.

Some drive systems employed on tunnel washers have large chain and sprocket design. This is normally associated with an automatic oiler or greaser that is critical to provide lubrication to the drive mechanism. Additionally, a drive failure with this system will result in the tunnel washer being inoperable until the drive can be repaired.

Chemical Injection

Chemicals are introduced into the Braun BTW via injection spades that penetrate the chamber seals above the water line. Through these spades, chemicals are rinsed thoroughly into the tunnel cylinder with water and/or chemical flush streams. Injection spades can be set up for any chamber on the BTW. **Figure 6** shows a chemical injection spade with a fresh water flush:

Figure 6—Chemical injection manifold and flush water

1. Injection Spade
2. Chemical Injections Ports
3. Flush Water Line

Machine Features (continued)

Rapid Drains

Rapid Drains are located in each bath exchange chamber. They consist of pneumatically actuated pistons that, when extended, penetrate the chamber seal creating a 80-100 GPM drain. The duration of the drain and the number of drain events per cycle are programmable. **Figure 7** shows an external view of the rapid drain, while **Figure 8** shows an internal model of the rapid drain in both the extended and retracted position.

Figure 7—Rapid drain

1 Rapid Drain
2 Shroud Drain

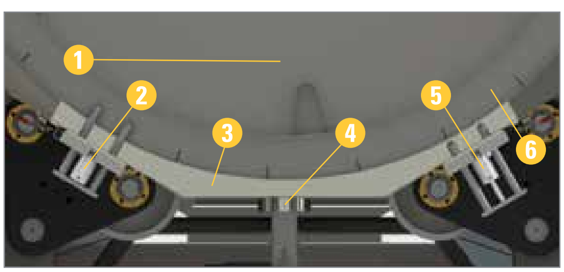


Figure 8—Rapid Drain

1 Wash Chamber
2 Rapid Drain Extended
3 Shroud
4 Drain
5 Rapid Drain Retracted
6 Waterway

Heating System

The heating system on the Braun BTW is designed for the application of steam to the machine in three different ways. Each of the heat applications on the machine are designed for the highest energy efficiency conversion, as well as for the quickest ramp up to operating temperature. The methods of heating are noted below including heating applications of each method:

1) In-tank Heating

- utilized for heating reclaimed water in the wetout tank and final rinse reclaim tank
- heating system sized to meet all industry demands
- energy efficient direct steam tank injection
- temperature probe in tanks for indication feedback
- precision temperature control

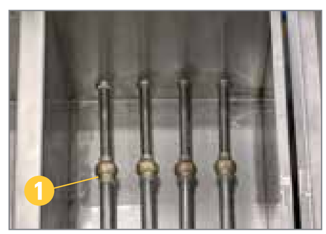


Figure 9—In-tank heating

1 Steam Injectors

2) In-line Heating

- utilized for heating all prewash compartments and main wash flow can be used for supplemental or primary heating of prewash compartments
- primary heating for main wash flow
- energy efficient direct steam line injection in process line while fluid being transferred
- temperature probe in pipelines for indication feedback
- precision temperature control

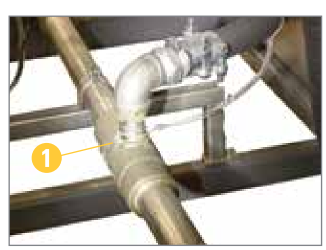


Figure 10—In-line heating

1 Steam Ring

3) In-shell Heating

- **patent pending** technology
- utilized for heating all necessary wash compartments
- energy efficient direct steam injection in BTW cylinder to get direct delivery of heat to process
- temperature probe in shell for indication feedback
- precision temperature control
- provides heating capability in one finish compartment for improved extraction and/or starch applications

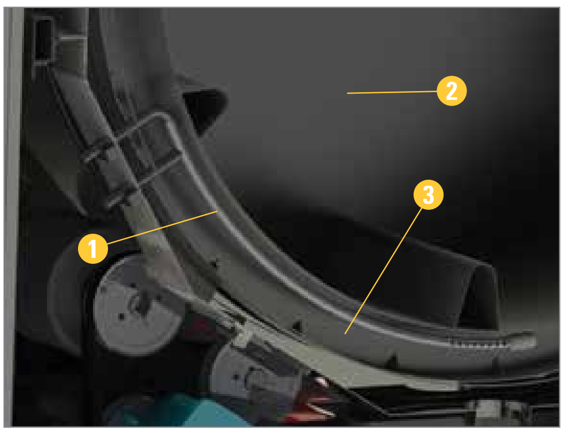


Figure 11—Sparge tube in tunnel waterway

1. Sparge Tube
2. Tunnel Chamber
3. Waterway

Water and Heat Recovery

The Braun BTW is supplied with internal heat and water recovery systems. Some of these features have already been noted in the overview section. Much of the recovered water is heated, so a by product of this is a reclamation of the heat from the machine also. Braun's total water recovery system (BTWRS) recovers seal wetting water, all process water, press cooling water, as well as other controlled cylinder overflows on the machine. The tanks and recovery equipment noted below are designed entirely for reclamation of process water and heat:

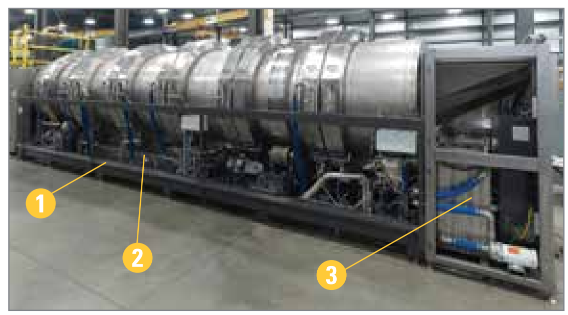


Figure 12—Entire tunnel with tanks shown

1. Final Rinse Reclaim Tank
2. Rinse Reclaim Tank
3. Wetout Tank

1) Wetout tank (recovers press and rinse process water and feeds to prewash zone)

Figure 13—Wetout Tank

1. Process Water Add
2. Bath Exchange Supply Pump

2) **Rinse Reclaim Tank** (recovers rinse process water and post wash bath exchange process water and feeds to wetout tank and wash zone)

Figure 14—Rinse Reclaim tank

1 Rinse Drain

2 Post Wash Bath Exchange

3) **Final Rinse Reclaim Tank** (recovers finish process water and feeds to post wash bath exchange)

Figure 15—Final Rinse Reclaim tank

1 Post Rinse Bath Exchange

4) **Press Water Recovery Tank** (recovers press process water and feeds to wetout tank, rinse zone and finish zone)

Figure 16—Press moat with pumps

1 Press Water Pumps

In addition to the meticulous design for water and heat recovery, tools are provided on the Braun BTW to measure and monitor water and steam usage in the field. Each machine is supplied with a total water flow meter to capture all fresh water used in the machine. The total water consumption is measured and used to calculate a gallons per pound ratio in the PLC processor. There is also an optional total steam flow meter to quantify all steam used in the machine. This number is converted from pounds per hour (measured) to BTU/hour (calculated in PLC processor). Field performance data for the Braun 150/220 BTW shows usages in the following ranges:

Water usage: 0.4 – 0.8 gallons per pound of linen with rewash percentage < 2%
Steam usage: 300 – 400 BTU per pound of linen

Transfer Method

The Braun BTW's open helicoid design, coupled with the bottom transfer process, results in the transfer of both water and goods from one chamber to the next without plugging and roping.

Transfer Method and Wash Process

Defined as the means in which a tunnel washer transfers a load of goods from one chamber to the next. There are two main types of transfer methods: bottom transfer and top transfer. Defined further, there are two different techniques used in bottom transfer: open helicoid and Archimedean screw. This section describes the transfer method of the Braun BTW and the differences between each method. A direct comparison of the three methods are in **Appendix 1.**

Logically, bottom transfer gets its name because the goods are transferred from chamber to chamber along the bottom of the tunnel cylinder. Similarly, a top transfer tunnel achieves this transfer by scooping the goods up and advancing them through a restrictive opening that runs through the center of the tunnel. There is a clear difference in philosophy between the two main transfer types, but there is also a stark difference in the two types of bottom transfer methods (open helicoid and Archimedean screw).

The Braun BTW uses an open helicoid design. Helicoid is defined as follows:

"A surface generated by a curve which is rotated about a straight line and also is translated in the direction of the line at a rate that is a constant multiple of its rate of rotation." [1]

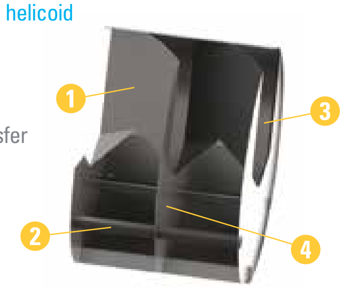
The BTW open helicoid members have a low angle curvature and large open area near the centerline of the machine. This combination allows free transport of the chamber contents without interference.

The transfer members do not contact the goods until the wash cycle time is complete, and when the transport operation is initiated they will be rotated into position to move the goods and water from one chamber to the next. **Figure 17** shows both the internal dividers and transfer helicoid members.

Figure 18 demonstrates the actual transfer process.

Figure 17—Internal open helicoid

1. Helicoid
2. Rib
3. Open Area for Transfer
4. Divider



Worth noting beside the large open area for transfer are the straight chamber dividers. The design of these dividers and ribs create a washing environment similar to that of an open pocket washer. This is a main difference between the Braun BTW open helicoid and the Archimedean screw. The Archimedean screw is designed like a corkscrew with angled dividers, which causes the goods to move axially throughout the process time. Additionally, for structure, the Archimedean screw features a large center shaft that runs the entire length of the cylinder. The axial movement of goods, coupled with the restrictive chamber volume caused by the center shaft, creates a greater probability of goods roping and tangling.

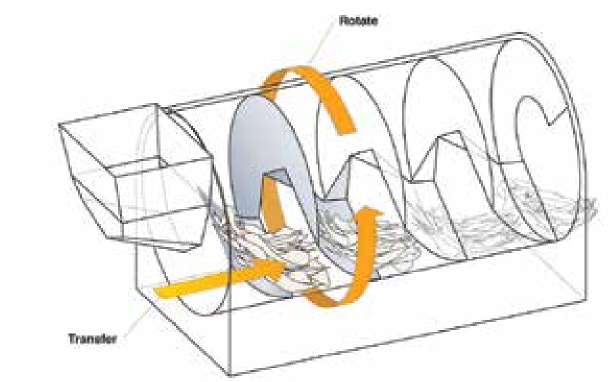


Figure 18—Bottom transfer/open helicoid

The Braun BTW's open helicoid design, coupled with the bottom transfer process, results in the transfer of both water and goods from one chamber to the next without plugging and roping. Additionally, all of the energy in the rotational operation goes into agitating the goods in solution as there is no axial movement of the laundry during the washing process (as is seen in the Archimedean screw machine types).

1 McGraw-Hill Dictionary of Scientific and Technical Terms, Fifth Edition; New York, 1994 (pg. 918).

Washing and Rinsing Processes

There are a number of parameters that are important for effective washing. These are mechanical action, temperature, chemistry, and time. This is commonly referred to as the wash pie and will be discussed in more detail as this section develops. Another important factor is adequate dilution. Dilution is the weakening of the soil concentration in the goods through the addition of cleaner water. This is important for the washing process as well as the rinsing process. Different tunnel designs try to accomplish dilution in different ways. This section explains how the flows in the tunnel washer are designed to achieve the greatest washing and rinsing effectiveness.

Counter Flow

Braun's BTW process includes what is known as counterflow. This is more commonly known as cascade flow and the concept is that cleaner process water is forced in the opposite direction of the main flow of material. Cascade flow has been proven to be an effective mode of rinsing and washing, and is often the method of choice when designing process plants. To gain an appreciation for cascade technology a definition of cascade mixing-settling is noted below:

"Series of liquid holding vessels with stirrers, each connected to an unstirred vessel in which solids or heavy immiscible liquids settle out of suspension; light liquid moves through the mixer-settler units, counterflowing to heavy material, in such a manner that fresh liquid contacts treated heavy material, and spent (used) liquid contacts fresh (untreated) heavy material." [2]

Counterflow is also a process that varies depending on the cylinder design of the tunnel washer. In a bottom transfer single drum design, the internal chamber dividers in the counterflow zones are perforated. This allows water to flow freely, by gravity, through the goods in each chamber of the zone. The necessity of water to pass through the goods creates an environment which ensures thorough dilution. This type of counterflow is called direct counterflow. In a top transfer double drum design, water is piped externally from the bottom of the outer drum in one chamber to the bottom of the outer drum in the next chamber. By introducing the water in the bottom of the chamber, the water must act against gravity to try and penetrate the perforated inner drum as well as the goods. This need to defy gravity runs the risk of a counterflow in which the wash liquor does not fully enter the washing chamber (the inner drum), resulting in poor dilution. This type of counterflow is called indirect counterflow. See **Appendix 1** for a direct comparison of the counterflow processes.

Direct counterflow is used in both the wash and rinse zones in the Braun BTW and is noted in the previous overview section. Water is injected in the last chamber of a given zone and flows to the first chamber of the same zone. The counterflow transports the dissolved and suspended soil in the water stream in the direction of the most contaminated process water, towards the drain in that given zone. Using counterflow in both the wash and rinse zones is known as dual counterflow.

Figure 19 depicts the effect of dual-direct counterflow:

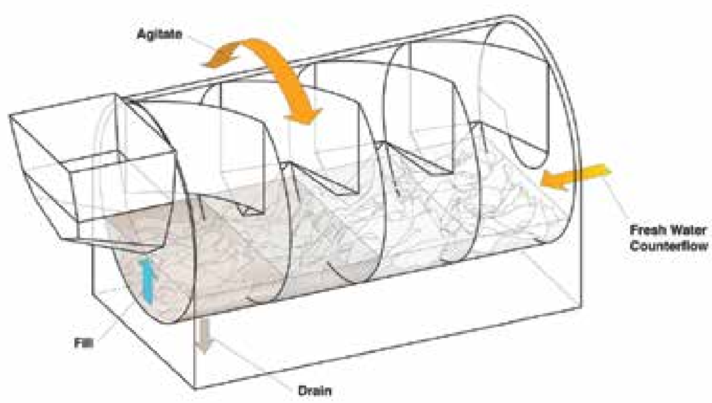


Figure 19—Counterflow diagram

2 McGraw-Hill Dictionary of Scientific and Technical Terms, Fifth Edition; New York, 1994 (pg. 320).

Important features about dual-direct counterflow:

1) Process water at the back end of the machine is the cleanest and moves dissolved and suspended solids (soil) to the front of the machine in both the rinse and wash zones.

2) Process water is forced through all of the goods mass over the entire length of the given chamber in both the rinse and wash zones.

3) Process water flows through the compartment walls, the only entry in the compartment, which eliminates the need for internal seals.

4) The result of dual-direct counterflow is a more consistent chemical gradient within each zone which minimizes linen damage and redeposition.

Another benefit to the Braun BTW is that the wash and rinse flows can be set and controlled by formula to provide the optimum process flow for each goods type. If process flows are minimized, cost savings in water as well as chemicals that are discharged down the drains can be realized.

The combination of flow control, Dual Counterflow, and Direct Counterflow makes for an effective rinsing and washing process, allowing plant operations flexibility for any application.

Bath Exchanges

Braun's bath exchange technology is important for tunnel processing. There are bath exchanges strategically placed in the prewash, post wash, and finish sections on all Braun BTW's. The bath exchange is a dual use chamber consisting of rapid drain and refill capabilities. They provide breaks between zones to remove spent process water prior to entry to the next zone.

The quantity of bath exchanges and their functions will depend on the number of chambers in the BTW. Each bath exchange and its functions and benefits are summarized below:

1) Pre wash bath exchange:

- removes soil laden process water early in process for heavy soiled goods to jump start the washing process
- refills with wetout water after initial draining of soiled process water
- programmable times for flexibility in processing needs
- up to 3 drain and refill events can be programmed for each tunnel transport cycle

2) Post wash bath exchange:

- removes alkali laden process water after the wash zone
- refills with final rinse reclaim water after drain to initiate rinsing process
- programmable times for flexibility in processing needs
- up to 3 drain and refill events can be programmed for each tunnel transport cycle

3) Finish bath exchange:

- removes rinse water prior to application of finishing chemicals to save chemistry
- refills with fresh water to remove finish chemicals towards end of cycle
- programmable times for flexibility in processing needs
- up to 3 drain and refill events can be programmed for each tunnel transport cycle

Wash Pie

The washing process is a combination of a number of controlled factors that are balanced. This is commonly known as the wash pie and is defined in the TRSA's Textile Laundering Technology.[3] An equally balanced wash pie is shown in **Figure 20** (adapted from TRSA by Braun):

As the wash process discussion develops, scenarios will be presented that alter the individual contributions of each component. This will be to demonstrate the flexibility offered by a Braun BTW to accomplish the washing process objective effectively.

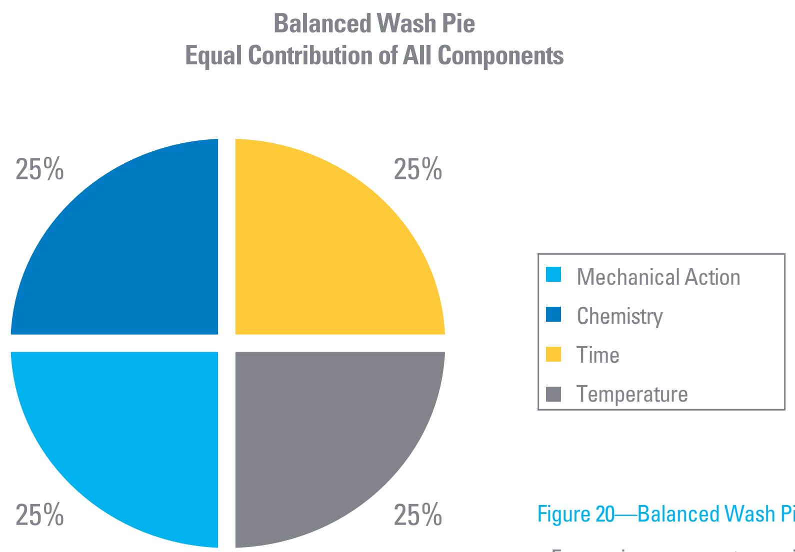


Figure 20—Balanced Wash Pie

- Four main components required for proper linen processing
- Changes in processing for any one component will require compensation by one or more other components
- This is representative of an ideal process with optimum balance of all four components

3 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pp. 24-27.).

Chemical Profile

Chemistry is the first piece of the Wash Pie and is an integral part of the wash process. It also represents a large part of the monthly expense of processing laundry. The Braun BTW process flow and control features discussed will result in a consistent chemical profile throughout the wash zone. This is due to the bottom transfer design combined with the direct counterflow through the goods. Consistent alkali gradients are favorable for less damage to the linen being processed, specifically polyester based linen. A top transfer tunnel washer demonstrates more variability in alkali concentration, specifically high concentrations early in the wash zone.

Figure 21 contrasts a typical alkali concentration gradient in the wash zone for a Braun BTW and a top transfer tunnel. The Braun BTW curve is based on a model validated with field test data. After the wash zone in the BTW, the bath exchange is employed to drain and refill the chamber to aggressively begin the rinsing process.

If alkali concentrations are excessive; alkali hydrolysis may occur, which is an attack of the caustic material on the fibers. This is described as follows:

"Polyester, on the other hand, can be damaged in strong alkaline solutions. The fiber surface becomes pitted and/or the fabric loses strength-a chemical process termed ***alkaline hydrolysis.*** All the conditions that lead to alkaline hydrolysis haven't been firmly established, but a combination of higher pH and temperature causes the greatest damage and in some cases, can destroy the polyester fiber. 'Spike' alkalinity, immediate concentrations after chemical dosing, may produce an adverse effect, and considerations should be taken. In any case, alkalinity should be thoroughly rinsed from the fabric and final pH adjusted so no residual is left in the fabric where it can be exposed to high heat from ironers or dryers." [4]

The above excerpt not only discusses the importance of low alkali concentrations, but also the importance of rinsing for minimizing goods damage. Test results from a leading chemical supplier in a field healthcare environment independently verified an excellent BTW rinsing process with a combination of dual counterflow and bath exchange technology as shown in the test data below:

Residual iron: Negative
Residual softener: Negative
Residual bleach: Negative
pH of fabric: 7
Note: A pH of 7 is neutral

BTW vs. Transfer Alkali Gradient

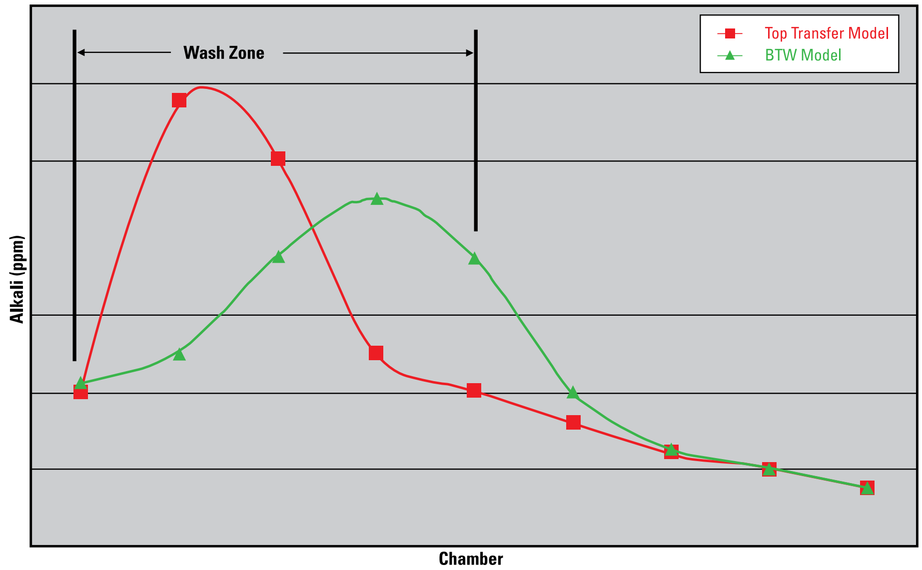


Figure 21—Typical Chemical Gradient in Braun BTW and top transfer tunnel

4 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pg. 186).

Mechanical Action

The combination of flow control, Dual Counterflow, and Direct Counterflow makes for an effective rinsing and washing process, allowing plant operations flexibility for any application.

Mechanical action is an important component in the wash pie. Braun's BTW is designed for robust and adjustable mechanical action. We have taken our industry leading washer extractor technology and applied this to the cylinder design of the tunnel washer. Each chamber washes with a similar level of mechanical action to a conventional washer-extractor for exceptional wash quality. Each chamber has three ribs that are spaced 60 degrees apart from each other to cover a third of the chamber circumference. The center rib is the tallest of three ribs and as the goods come into contact with this a lift and drop action is affected, similar to a conventional washer extractor. To fine tune this component of the wash pie, an adjustable wash angle is also a feature on the machine. The wash angle can be adjusted to optimize the action desired for the tunnel processes.

The wash angle setting correlates to a rotational angle as noted in **Figure 22:**

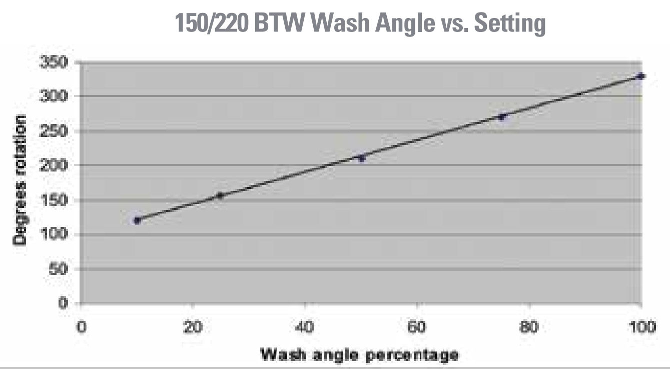


Figure 22—Wash angle percentage setting and actual wash angle

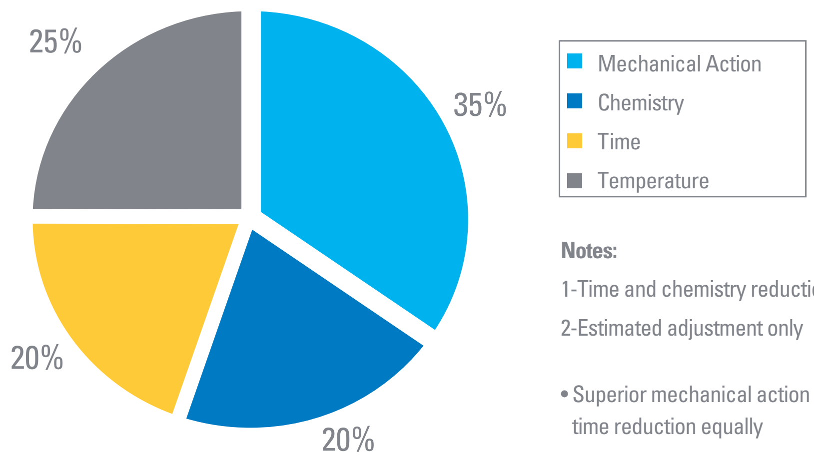
There is also a long and short wash angle setting so specific goods types can be programmed with an intentional gentle angle so as not to over agitate and damage the goods and/or redeposit removed particulate. Degradation in whiteness can be seen if there is too much mechanical action. Field testing on Braun BTW's has shown that the whiteness retention is better than typical standard samples. Testing results are summarized below. Test 1 was conducted independently by a leading chemical vendor and test 2 was carried out using Laundry Performance Evaluation test pieces from the Dry-cleaning and Laundry Institute (DLI):

	Test 1	Test 2
Industry standard	100.0	100
Braun average	104.9	103

The fact that Braun BTW's have robust as well as adjustable mechanical action (i.e. a wide process window), allows plant operations latitude to tune the process to that which best meets the requirements of the facility. This flexibility allows the operator to slightly adjust the wash pie segments to best suit the processing needs. The Textile Laundering Technology handbook demonstrates wash pie segment shifts emphasizing reduced time, temperature, and chemical costs.[5] The Braun adjustable BTW mechanical action allows the operator the luxury of widening the process window to reduce other segments of the wash pie. Temperature is typically not an option due to minimum activation energy required for many chemical reactions. Peroxide bleaching is an example of this. Two scenarios are demonstrated in **Figure 23;** reduced time and concentration, and reduced time only:

5 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pp. 25-26.).

Braun Mechanical Action—Scenario 1



Notes:

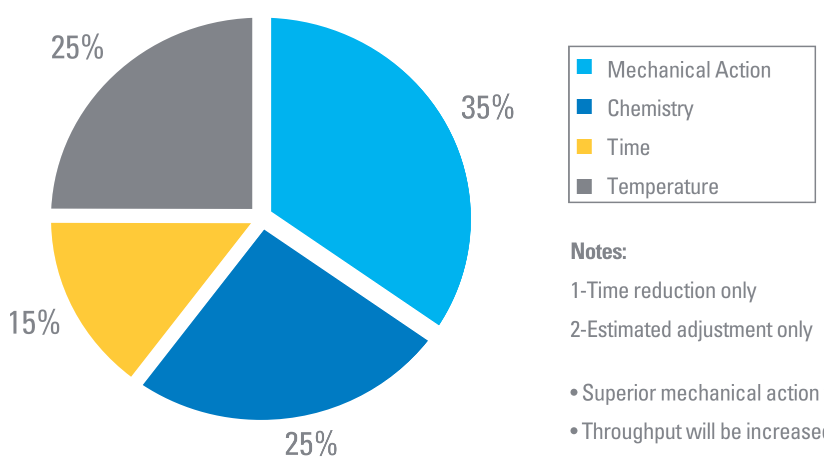
1-Time and chemistry reduction

2-Estimated adjustment only

- Superior mechanical action allows chemistry and time reduction equally
- Shift in pie works to a cost and throughput advantage
- No additional cost as inherent feature of machine
- Controllable parameter with wash angle adjustment capability

Figure 23—Modified Wash Pie Scenarios

Braun Mechanical Action—Scenario 2



Notes:

1-Time reduction only

2-Estimated adjustment only

- Superior mechanical action with wash pie adjustment in time only
- Throughput will be increased at no additional cost
- Controllable parameter with wash angle adjustment capability

Wash Testing Results

Results for whiteness retention testing performed on Braun BTW's were already discussed previously. Additional field testing using Laundry Performance Evaluation test pieces from DLI has been performed to evaluate the wash quality of the Braun BTW process with the following results (compared with Industry standard):

Percent better than standard.	
Tensile strength loss	62.0%
Yellowness	90.0%
Soil removal	24.3%
Bleach effectiveness	5.8%

Table 2—Batch tunnel washer production rates

	BATCH WASHER PRODUCTION RATES				
Number of chambers	8	10	11*	12	14
Total wash time (min)	Production Rate (lbs/hr @ 100% efficiency)				
14	5,143	6,429	7,072	7,714	9,000
18	4,000	5,000	5,500	6,000	7,000
22	3,273	4,091	4,500	4,909	5,727
26	2,769	3,462	3,808	4,154	4,846
30	2,400	3,000	3,300	3,600	4,200
34	2,118	2,647	2,912	3,176	3,706
38	1,895	2,368	2,605	2,842	3,316
42	1,714	2,143	2,357	2,571	3,000

* Constructed based on data for an 11 chamber tunnel washer

5 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pp. 25-26.).

Sizing

Correct tunnel sizing is paramount to an efficient and successful operation. Many factors need to be evaluated in this decision. One essential factor is desired throughput and how that relates to quality. The recommended throughput differs with the size of the machine.

Braun offers three sizes for both tunnel washer classes; an 8 chamber, 11 chamber, and 14 chamber. There are target cycle times and ranges for each of these machines based on total dwell time in the machine. The ranges can change based on soil level.

When choosing a tunnel, it must be remembered that the less compartments a tunnel has, the greater the cycle time needed to achieve effective washing. Choosing to run a smaller compartment tunnel with cycle times lower than the recommended ranges leads to issues with quality and longevity of goods, as well as increased operating costs. This is a direct result of the wash pie discussion in the previous section. Because of the reduced wash time available in a smaller tunnel coupled with short processing times, higher chemical usage is required.

Textile Laundering Technology defines tunnel throughput based on size and total wash time. Average production rates for 150 pound batch sizes are shown in **Table 2 (on page 16).** An additional column was constructed based on the data for an 11 chamber tunnel washer.[6]

The cells that are within the setup range for typical light to medium soil for a bottom transfer washer are highlighted in grey for reference. These are taken from a table of industry standard process times for hotel sheets, hotel and hospital linen, and general hospital linen.[7] The tunnel washer should be sized based on these throughput numbers to best insure success for the overall tunnel system productivity.

Undersizing any type of tunnel will lead to unachieved throughput goals and excessive operating costs. To better understand these consequences the pie chart is used as the foundation for this discussion. To achieve satisfactory washing, based on the wash pie chart **(Figure 20),** if time is sacrificed then other areas of the chart must increase. A by product of the reduced time is also a reduction in mechanical action since there will be less oscillations in a given tunnel cycle. It has also been mentioned in this technical bulletin that temperature is typically not an option to adjust due to minimum activation energy required for many chemical reactions. The only option this leaves is to increase chemical concentration in order to establish wash quality.

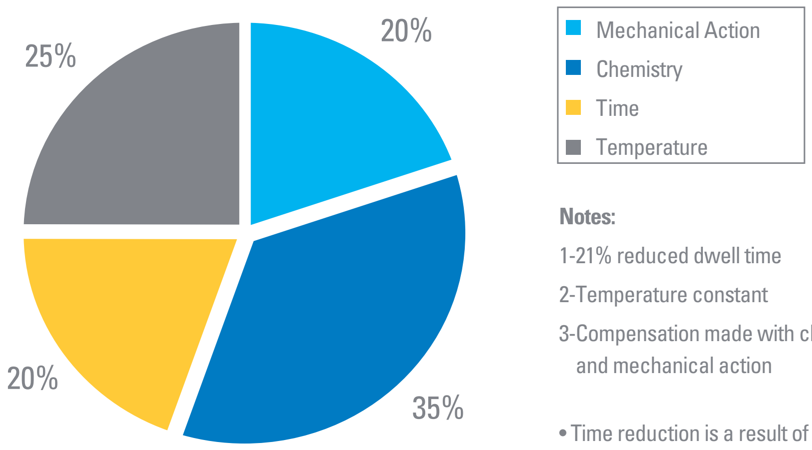
With an undersized tunnel, the dwell time in both the wash and rinse zones decreases. To combat this, some rinsing needs to start at the end of the wash zone, which lessens washing effectiveness. To compensate for this reduced dwell in the wash zone higher chemical concentrations at the beginning of the wash cycle are employed. This chemical spike has two direct consequences. First, the higher concentrations lead to greater chemical costs for the life of the machine. Secondly, as referenced earlier in this technical bulletin, the higher concentrations reduce the tensile strength and life of the goods, which also results in a greater linen replacement cost.

6 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pg. 157).
7 Riggs, Charles L.' Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pg. 155).

Applications (continued)

The two graphs in **Figure 24** show how this scenario skews the wash pie and the adjustments that are required as a result:

**Adjustments required for improper sizing from balanced model—
Large vs. Medium Chamber Numbers (1.5 minute cycle)**



Notes:

1-21% reduced dwell time

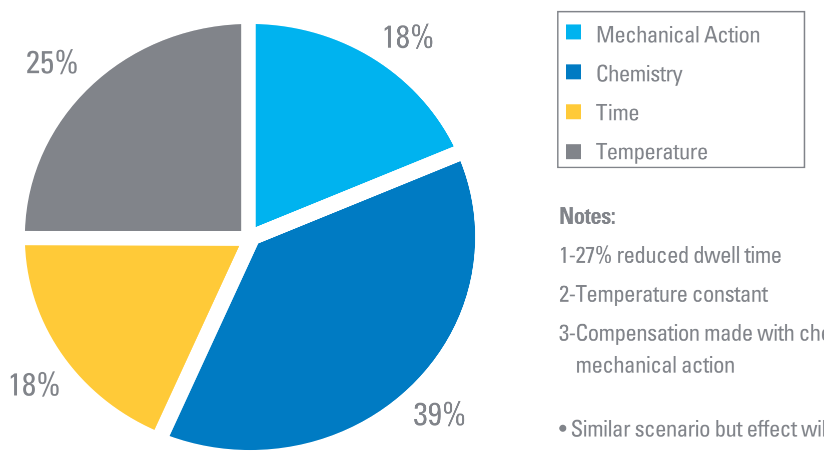
2-Temperature constant

3-Compensation made with chemistry to offset reduced time and mechanical action

- Time reduction is a result of less number of chambers at fixed cycle time
- To maintain desired throughput an increase in chemical concentration will be required
- A secondary effect will be an increase in rinsing required to remove additional chemicals required for processing

Figure 24—Adjustment scenarios required for improper sizing

**Adjustments required for improper sizing from balanced model—
Medium vs. Small Chamber Numbers (2 minute cycle)**



Notes:

1-27% reduced dwell time

2-Temperature constant

3-Compensation made with chemistry to offset reduced time and mechanical action

- Similar scenario but effect will be greater based on greater percentage
- Chemical concentration increases will be forced even higher than larger machine scenario
- Rinsing will need to be increased in this scenario to a higher level than smaller machines

Overall System and Processing Considerations

The tunnel washer is the backbone of the tunnel washing system and has been the topic of discussion in this technical bulletin. That being said, each of the individual components in the system has an important role in the overall system processing capability. When the tunnel washer is setup with reasonable wash processing times, if the other components are not setup or tuned properly, the overall system will not perform as expected. System efficiency of 100% is not realistic and must be tempered by real life factors. Textile Laundering Technology notes four factors that are qualifying considerations for the throughput numbers shown in the batch tunnel washer production rate table as[8]:

"- Rates shown..... require that sufficient capacity of downstream equipment such as extraction and/or drying be available.

- Production may be less due to NOG goods creating more under loaded batches

- Production may be less if empty pockets are required between greatly dissimilar batches.

- Production or Wash Quality may be reduced, and costs increase, if efficient sequencing is not maintained."

These are very important factors that are often overlooked when designing and specifying a tunnel system. An article in Textile Rental Magazine states this well as when it notes that:

"There is a long history in our industry of continuous batch washing systems not performing to their maximum capabilities for one simple reason: They weren't designed with the concept of linear (series) production as the primary focus of the design" [9]

The article goes on to identify two of those downstream components that hinder performance as "not providing adequate high-pressure extraction time" and "not providing adequate drying capability".[10] This section will address the overall system operation.

The components of the system that need to be addressed individually for a tunnel washing system are noted in **Table 3 (on the next page).** In the table the specific considerations that have to be taken into account are identified.

When the overall system is setup and operated properly, testing can be performed after initial ramp up to determine if productivity can be improved beginning with the tunnel cycle time reduction. As an example of this, at an operating plant with a 150 BTW-11 tunnel washer system, tunnel cycle time was able to be reduced well below the lower limit setup targets for an 11 chamber machine. Tunnel transport time was ultimately lowered to 103 seconds (35 transfers/hour) for a hospitality linen plant. The recommended setup time for an 11 chamber machine based on table 2 is a minimum of 22 minutes. The machine runs a total process time of just under 19 minutes for most of the goods types processed. The throughput achieved was a bonus and due to proper tunnel system design and excellent operations management. The results of these improvements are noted as follows:

- Excellent goods quality
- Process balance
- Process throughput efficiency
- Cost parameter control (natural gas, water, and chemicals)

8 Riggs, Charles L., Ph.D. and Klipper, Michael, Textile Laundering Technology, Alexandria: 2005 (pg. 158).
9 Curiale, Jim. Textile Rental, February 2009 (pg. 64).
10 Curiale, Jim. Textile Rental, February 2009 (pp. 64-65).

Applications (continued)

Table 3—Tunnel system component optimization

Component	Options	Considerations
Load device	Sling	-generally less labor intensive after slings are loaded in soil sort area -less interference at ground level with operation -goods cueing and staging based on cycle times, goods type is important for overall operation
	Conveyor	-manually loading requires adequate labor resource management to not slow system down -goods cueing and staging based on cycle times, goods type is important for overall operation
Tunnel	General	-tunnel considerations discussed extensively in the applications section -heat application in finish end will reduce moisture in pressed cakes -do not necessarily want to run the tunnel as fast as possible for overall system performance optimization -transport time is an important component in addition to cycle time (may not be included in overall tunnel cycle) -although the key piece of equipment in the system, do not neglect importance of each other component
	Number of modules	-specify number of modules on the conservative end of throughput requirements -tunnel considerations discussed extensively in the applications section and always lean towards slight over capacity side for safety
Press	General	-understand moisture extraction curve performance to assess minimum time under high pressure -poor moisture extraction is very costly as water removal in dryers requires more energy per pound -tamping feature can be beneficial for low permeability goods types (gowns, high fiber count sheets, etc) -dead time parameters should be adjustable for press-tunnel cycle optimization matching
	Pressure	-pressure at the membrane is actual pressure on the linen matrix, measurement and control of pressure at the membrane is the preferred method -40 bar and above units provide more than enough extraction force
	Basket diameter	-larger diameter is desirable -use height to area ratio as a rule of thumb for sizing as the lower this ratio is the better the extraction becomes
Cake handling shuttle	Single Bed	-limits buffer capability for press-dryer interface -simpler operation
	Double Bed	-best for double cake dryer setup -best for buffer capability for press-dryer interface -front end goods cueing is more important for matched goods
Cake storage elevator	Single Bed	-limits buffer capability for press-dryer interface -simpler operation -does not use shuttle movement as efficiently with full travel for every cake
	Double Bed	-best for double cake dryer setup -best for buffer capability for press-dryer interface -front end goods cueing is more important for matched goods
Sheet by pass station		-option provides additional system capacity to mitigate system from becoming dryer bound
Clean side rail storage		-Braun Patent Pending technology provides rail storage and chute loading of dryers -provides additional storage buffer capacity to eliminate process flow bottlenecks
Dryers	Single cake	-reduced opportunity for mixed cake loads -adds more time per cake for ancillary operations (load, lint blowdown, unload) -design system with correct number of dryers with additional if possible (downtime, unforeseen issues)
	Double cake	-more sensitive to mixed loading issues -less time per cake for ancillary operations (load, lint blowdown, unload) -design system with correct number of dryers with additional if possible (downtime, unforeseen issues)
Unload conveyor		-clearing of goods either manually or automatically is primary concern -labor resource management important to ensure operation is not a bottleneck

Goods Processing Flexibility

The Braun BTW can be utilized in most any processing application. Due to its design, process control features, multiple heating zones, and chemical injection flexibility, it can be setup to effectively process a wide range of classifications. As a result, any laundry processing plant can benefit from Braun's technology. A brief summary of which features would be used for five main types of processing plants is noted below:

Healthcare:

- flexible front end temperature for lower prewash temperature requirements
- can use trim heat in prewash if chemistry warrants additional front end heat
- high or low temperature wash zone capabilities:
  - easily can reach 180°F for peroxide bleaching
  - lower temperature control excellent for PAA and enzyme washing chemistries (120 - 140°F)
  - heat control and/or indication in every wash zone chamber
- multiple rapid drain and refill capabilities in the prewash zone for heavy soil products
- post wash bath exchange for aggressive pre rinse and/or application of rinsing chemicals
- finish heat for reduced moisture in pressed cake

Hospitality:

- trim heating in prewash section for higher heat application:
  - can hit up to 190°F with trim heating
- high or low temperature wash zone capabilities:
  - easily can reach 180°F for peroxide bleaching
  - lower temperature control for chlorine bleaching (140 - 160°F)
  - heat control and/or indication in every wash zone chamber

Hospitality (continued):

- flexibility with goods type shifts:
  - prewash and post wash bath exchanges for rapid drop of undesired process water
  - can program to allow empty pockets before and/or after goods needing segregation
- post wash bath exchange for aggressive pre rinse and/or application of rinsing chemicals
- finish heat for reduced moisture in pressed cake and starch applications

Food and Beverage:

- multiple rapid drain and refill capabilities in the prewash zone for heavy soil products including heavily soiled and stained table linen and bar mops
- flexibility with goods type shifts:
  - prewash and post wash bath exchanges for rapid drain of undesired process water
  - can program to allow empty pockets before and/or after goods needing segregation
- finish heat for reduced moisture in pressed cake and starch applications

Industrial:

- trim heating in prewash section for higher heat application:
  - can hit up to 190°F with trim heating
- multiple rapid drain and refill capabilities in the prewash zone for heavy soil products including industrial wipes

Scour Bleaching:

- high temperature capability in prewash for scour processing (up to 190°F)
- high temperature capability in wash for peroxide bleaching process (up to 205°F)
- finish heat for reduced moisture in pressed cake and softener process

Summary

Batch tunnel washers are an excellent option for high volume, efficient goods processing. Braun BTW's are designed to be flexible, simple and effective to meet any plant processing needs. The machine operation and process flow is designed for optimal wash processing of any goods type desired. Water and heat reuse is applied throughout the machine, resulting in a cost effective use of natural resources. Simplicity and durability are the key words when describing the machine features. The cylinder, drives, seals, heating system, and water and heat recovery systems are designed to ensure high quality processing at the lowest costs, ease of maintenance and long life expectancy.

The open helicoid internal cylinder design allows for optimum washing as well as hindrance free transport. This is not only key to trouble-free processing, but ensures that personnel do not have to enter the tunnel to unplug jams. The cylinder volume is used efficiently for all rotational processes during the wash cycle.

Superior wash and rinse processing is mainly due to dual-direct counterflow and superior mechanical action. A result of this is a uniform alkali concentration gradient in the wash, rapid and effective rinsing, and increased throughput due to wash pie time reduction. It also allows for efficient use of chemicals and utilities thus minimizing plant operational expenses.

A properly sized tunnel will demonstrate excellent production throughput. Additionally, Braun's flexible machine features allow efficient processing in any of the five major goods classification type plants.

Science is the foundation for the development, design and validation of the performance of the Braun BTW.

It stands the test of time!

No matter what tunnel is being utilized, the downstream equipment is equally important to overall system performance. In the next sections, we'll present a brief overview on extraction methods, examine the dry process and finish up with a look at material handling solutions in the tunnel environment.

Tunnel System Extraction Methods

In general, there are two types of extraction methods used in batch tunnel systems. The first is a batch press extractor and the second method is a centrifugal extractor. We'll start by taking a brief look at the batch press extractor.

Press extractors are really quite simple machines as far as the function they perform. They accept a load from the tunnel into a round basket and then squeeze water out of the goods by means of a hydraulic ram with a rubber membrane attached. The actual process however is a bit more complex. Removing as much water as possible within the parameter of the programmed tunnel cycle time is a very critical aspect of the overall system performance as less moisture removed means longer dryer time or ironer slowdowns and reduced efficiency.

The press cycle as described above is governed by the overall cycle time of the tunnel. The press cycle must be programmed to be slightly shorter than the tunnel cycle so it is always ready when the tunnel cycle ends. Some manufacturers' presses link the controls together between press and tunnel allowing the press to stay in sync with the tunnel cycle. This may mean short-cycling the press to ensure it is ready for the incoming load. Unfortunately, many of the time functions of the press are fixed such as lowering/raising the basket, ram up/down movement, and cake ejection time. This typically leaves only the time under high pressure variable that can be adjusted, so shorter tunnel cycles inevitability mean less time under high pressure and thus more moisture left in the goods.

So how do you optimize the press for the highest moisture removal in the shortest time?

There are two ways manufacturers try to achieve this… larger baskets and/or higher maximum pressure. Each has their advantages and disadvantages. First lets take a look at enlarging the basket diameter to reduce the height of the cake. This allows water to more easily escape during the high pressure cycle of the press. However, as diameter becomes larger and larger and the cake height continues to reduce, resulting in uneven distribution of goods as they flow into the basket, which can become a problem. Therefore most manufacturers have settled into basket diameters for presses with rated load capacities of 150 - 250 lbs with press basket/membrane diameters of between 39 – 52 inches. However, as discussed above, a larger diameter isn't the complete answer. A balance of the right basket diameter (cake height) coupled with proper formula development affords the optimal relationship between pressure, time, material type, and moisture extraction.

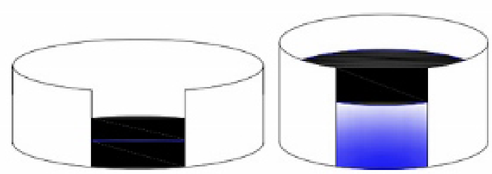


Figure 25—Basket and cake comparison

Increasing the maximum pressure definitely has advantages to a certain point. That point is reached when the maximum pressure at the membrane gets to between 40-45 bar. Above this pressure point, there is very little improvement in moisture removal, especially in a smaller basket diameter. Pressing laundry when confined in a basket creates an environment similar to a filter press. Water becomes trapped between the fibers and no amount of pressure within reasonable rates in a given time will increase the removal rate. Only time can allow this increase in pressure to work. The other disadvantage to running at higher maximum pressures is the increased wear and tear on the equipment and the linen.

Tunnel System Extraction Methods

Higher pressures also wreak havoc on different goods types ranging from setting creases to linen damage. Using pressures exceeding 45 bar will set creases in fabrics to include terry products. Unless the temperature of the water in the final rinse is kept at ambient (room temperature), these creases may be permanently set. The downside to holding rinse temperatures at room temperature is that using higher temperatures in the final rinse allows the fibers in the product to open up allowing for increased moisture removal. Holding rinse temperature at ambient isn't the only downside of using higher pressure presses.

As textiles continue to evolve, many new blends of polyester and cotton products are entering the market space; especially prevalent in higher-end hospitality products like sheets and pillow cases. When these blends and higher thread count products are subjected to pressures greater than 25 – 30 bar, these products can be permanently damaged with thread breaks called blowouts. Since water is incompressible, the high pressure from the extraction press causes the water to push through the tiny gaps between the threads resulting in small holes in the product. There are a number of ways to combat this and they all involve using less pressure or ramping up to a lower pressure setpoint very slowly. Another method is the use of tamp cycles, but this shortens the overall press time under high pressure resulting in less moisture removal and a possible slowdown at the ironers.

As can be seen by the discussion above, higher pressure isn't always the answer. Basket diameter, goods types being processed, and formula capabilities all need to be factored before making a decision solely on high pressure. ***Remember, high pressure isn't necessarily the best solution!***

The next type of extractor is the centrifugal extractor. This type of extractor uses centrifugal force identical to a washer to remove moisture from the goods. The tunnel transfers goods into the extractor and it begins to spin gradually ramping up to a high g-force extraction process. Much more time is needed to remove an equivalent amount of water as the press extractor, so tunnel cycles are typically programmed longer or multiple centrifugal extractors are required to match the shorter tunnel cycles. The extra extractor(s), conveyance devices and additional controls all factor in to additional capital costs for this type of system. However, some goods types cannot be extracted with the press extractor and force use of centrifugal extractors. An example of this would be processing walk-off mats in a tunnel in an industrial laundry. A press extractor would damage the mats, thus necessitating extraction be done in a centrifugal. Another example from the industrial laundry side might be uniforms. Buttons on shirts and zippers on pants may become damaged in a press extractor, although some can be processed in a press extractor at low pressure settings. Even if part of your goods mix involves these types of goods, there may be another solution that would allow faster cycle times in your tunnel and use of a press extractor.

An option might be to use washer extractors for the goods that can't be processed in a press extractor, while running the rest of your mix in a tunnel with a press extractor. This option depends on the percentage these types of goods makeup in the overall mix, and assumes that percentage can be handled by either existing washer extractors or by a relatively small investment in new ones. Taking these goods out of the tunnel and lowering cycle times may provide enough additional productivity to justify the added investment in washer extractors if the laundry doesn't already have them in place.

There is much more science behind the press and centrifugal extractors, and the reader is encouraged to look deeper into this science. However, the bottom line to extraction is:

It is significantly less expensive to remove water in the extraction process versus removing it in the dryers!

Unfortunately, extraction doesn't remove the need for dryers and the drying process. The next section covers the science behind the drying process in detail.

The Drying Process

Just like the wash process, the fundamentals of commercial textile drying haven't changed much over the years. The science is still the same, but technology has evolved allowing for greater energy efficiency and ease of dryer management and maintenance.

The drying process consists of four fundamental components temperature (or heat source), airflow, mechanical action (or tumbling), and time. All four must exist in order for the dryer to function efficiently.

When we covered the science behind the washing process, a simple model was used to depict the four major components of the wash process. Well the same can be done for the dry process. This model is called the "Dry Pie℠" and is shown in Figure 26.

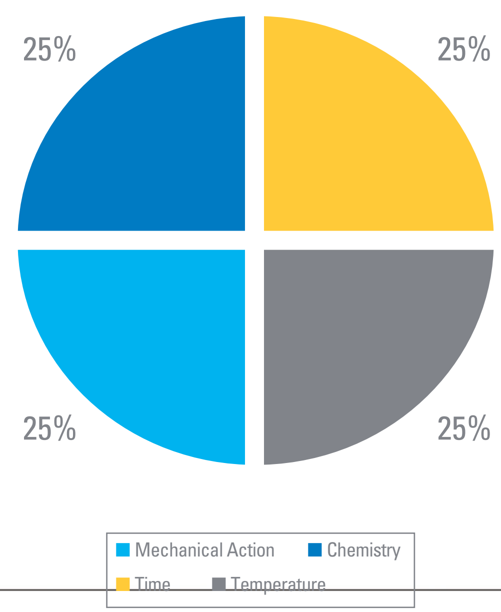


Figure 26—"Dry Pie℠"

Note: Trademark issued to G.A. Braun, Inc.

This publication will explain the science behind each element of the Dry Pie℠ so that the reader can understand how technology is used in the drying process. These four elements of the Dry Pie℠ allow the dryer to evaporate moisture from textiles in an efficient manner.

After a thorough review of these fundamentals, we'll dive deeper into the actual science behind each component to provide a solid understanding of how this science has helped technology evolve. The end user can benefit by understanding this science and applying it to track key performance metrics for the drying process.

Before we get into the science behind each of the fundamentals of drying, Figure 27 provides a summary on the relationship of energy usage in today's industrial dryers.

Where does the heat go?

1. It takes 970 BTUs/lb of H_20 @ 212° to evaporate water
2. It takes 1 BTU/lb to raise the temperature of water 1° F
3. It takes 0.02 BTU to raise each Cubic Foot of air 1° F
4. Heat absorbed by the dryer itself and not transferred to the textiles
5. Unburned gas (burner efficiency)
6. Losses from the lack of good sealing design and/or lack of preventative maintenance

Figure 27

So given the scientific facts presented in Figure 27, why is it that your industrial dryer consumes much more than 970 BTUs per pound of water removed?

This next section takes a look at the science behind drying technology and helps answer this question.

Temperature (Heat Source)

First, a dryer must have a heat source to generate Temperature. Temperature is the first component of the Dry Pie℠. This heat source is typically one of three types:

Natural Gas, Liquid Propane Gas, or Steam.

Lets briefly examine each source.

1. **Natural Gas (NG)** is by far the most common source of heat used in commercial dryers today. It is a very economical source of fuel for the dryer given today's pricing and the abundance of this resource domestically. However, pricing can fluctuate and having metrics to ensure your dryer is performing at peak efficiency is vital to long term cost avoidance.

2. **Liquid Propane Gas (LPG)** is another fuel source commonly used in commercial dryers. Propane prices can also fluctuate, so metrics are equally important to track. The main difference between NG and LPG is that LPG contains over twice the BTUs per cubic foot as NG (2,516 BTUs per cubic foot for LPG versus 1,030 BTUs per cubic foot for NG). So LPG will burn at a much higher heat rate per cubic foot consumed to the point that if the dryer gas train isn't compensated for LPG, serious damage can occur to the dryer and structures housing them. Users must ensure the dryer gas trains are properly adjusted for the type of fuel (NG or LPG) and that the dryer gas train is certified for both. Adjustments to the gas train are something the end user should have their dryer manufacturer perform if possible. Remember that misadjustments can lead to serious consequences up to and including a fire.

3. The third source is **steam**. Steam is not commonly used in the North America because of the availability of either NG or LPG. Also steam is much less efficient than the other two fuel sources. This is because of the BTU content of steam and the ability to convert that BTU content to usable energy to evaporate water. One pound of steam has 1,000 BTUs at 125 psi. The usual method to dry with steam is to pass air through steam coils heating the air to ~300 – 330 degrees F. Unlike NG or LPG, this is the maximum inlet temperature obtainable. NG and LPG can generate inlet temperatures exceeding 600 degrees F thus starting the evaporation process sooner and reducing cycle time.

Temperature is usually monitored in at least two locations during the drying process. These two areas are the inlet temperature, or temperature of the air entering the dryer basket containing the textiles, and the exhaust temperature, or the air temperature exiting the dryer basket. Inlet and exhaust temperature are both very important and drive the efficiency of today's modern dryers.

Inlet temperature is normally the higher of the two, and is a direct measure of the temperature of the air entering the drying vessel (or basket). It is typical to set the inlet temperature to a point where evaporation will take place as fast as possible without causing damage to the textiles being processed. The inlet temperature is a key setpoint when creating a dry formula.

The exhaust temperature is typically monitored by all industrial dryer controls. This temperature is set to a value representing the temperature the air stream exiting the dryer will stabilize at when the textiles are fully dry or reach a set percentage of moisture remaining (2% – 5%). It is almost always much lower than the inlet temperature, and is a key variable in the proportional-integral-derivative (PID) controllers used in today's modern dryers.

The importance of determining the correct values for these two temperatures cannot be overstated. They are the drivers behind getting the most efficient cycle possible for each type of product dried in the industrial dryer.

So how does the end user determine these temperatures?

Each textile product has a suggested dry temperature setting shown on the product tag that is attached to it. Most textile manufacturers publish these dry settings on their websites and in their literature. **The most important take away from this discussion is that one setting will not work for all goods types.** Cotton for example can handle fairly high inlet and exhaust temperatures. As an example, 100% cotton terry towels could handle a 600 degree F inlet and 190 degree F exhaust (this may vary depending on the specific OEM's solution utilized). Scorching won't be seen on cotton terry until approximately 700 degrees F. On the other hand, microfiber towels that have become very common in the industry must not be exposed to a temperature above 160 degrees F or damage to the fibers will occur. The last example is walk-off mats. The mat manufacturers have conducted many studies, and their recommendation for maximum temperature is that the mats should see no more than 180 degrees F. This recommendation is to ensure the rubber backing and the mat fibers themselves do not break down due to thermal stress. These three extremely different temperature settings show the importance of doing the homework up front on products that will be run in the dryer before creating the dry formulas for them.

One "size" just won't fit all!

So how do these two temperatures interact with each other during a typical dry cycle?

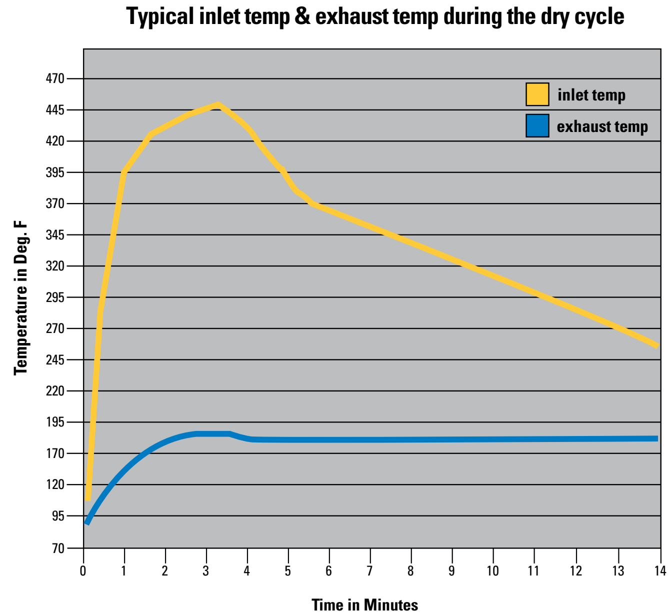


Figure 28—shows the inlet and exhaust temperatures charted during a typical cycle running 100% cotton terry towels.

The first few minutes are consumed performing a number of different functions unrelated to the actual drying process. Typically during this time, a lint blowdown cycle may be conducted prior to burner ignition. A purge cycle is performed to ensure no combustible gases remain in the combustion area prior to igniting the burner. Lastly, time is needed to heat the goods and dryer to get the temperature inside the basket to the evaporation point.

The example above is from a dryer using a modulating gas valve controller. This allows the dryer; using a predefined PID control, to automatically adjust the burner output precisely around the user's programmed formula setpoints for inlet and exhaust temperatures. When the inlet setpoint temperature is reached, the maximum amount of energy is being input into the dryer for that dry cycle, and thus the highest moisture removal takes place as water begins to evaporate at an increasing rate. In fact, 40% - 60% of the moisture in the textiles is evaporated and removed in the first 5 minutes of a typical dry cycle.

As the goods continue to dry, the reader can see in Figure 28, the inlet temperature curve decreasing as less and less energy is needed to continue the evaporation (drying) process. While the inlet temperature decreases over time, the exhaust temperature is stabilizing around the setpoint. The exhaust temperature is an indication of the actual temperature of the goods as they begin to dry. This will stabilize at the setpoint exhaust temperature once the textiles have reached a full dry condition. One very important factor to understand from this graph is the term **"Differential Temperature."**

Differential Temperature is simply the temperature difference between the inlet and the exhaust. At the far left side of Figure 28 at approximately one minute, the differential temperature starts at 265 degrees F (395 – 130). At the end of the dry cycle, this differential temperature has reduced to approximately 85 degrees F (265 - 180). Differential temperature is extremely important in that it allows the user to program the temperature when a load of goods becomes dry or has 2% - 5% moisture remaining. It is best to allow some moisture (2% - 5%) to remain in the textiles to allow for slight evaporation during time spent in the laundry. If the user finds that the goods are still a bit damp at the end of the cycle, a slight reduction in the differential temperature will allow the inlet and exhaust temperatures to become closer allowing for more drying to occur. On the other hand, if the goods are over dry, increasing the differential temperature will allow the dry cycle to end before overdrying takes place. Differential temperature is one of the most accurate ways to run each product formula. It is a much more efficient way to run the dry cycle versus using "Time," which will be looked at in more detail later in this section.

Airflow

The second component of the Dry Pie℠ is airflow. If we look at how textiles used to be dried, by being hung outdoors and allowing natural conditions to dry the goods, the importance of airflow becomes very clear.

Textiles can be hung in an open environment and exposed to natural or mechanically induced air currents. These air currents passing through the fibers coupled with natural temperatures above freezing allow water to evaporate and be carried out of the fibers allowing the goods to begin to dry. Without any airflow, goods hung outside on a calm day will take much longer to become dry than they will on a windy day.

This same principle is at work in an industrial dryer. A dryer must have a source to pull the heated air through the goods and a means to remove that moisture-laden air. This is typically done with a blower motor and wheel, which pulls air through the heat source into the vessel containing the textiles and then discharges that air out through ductwork outside the building. Much more detail on airflow will be presented in the next section.

Like temperature, ideal airflow will be different for different size dryers, load sizes and goods types, and a balance must be established between the variables to get the fastest drying times at the most efficient energy use rate.

Figure 29 shows the relationship between high and low airflow and the impacts each have on dryer efficiency. Namely, each has an impact on the BTU/lb of water removed rate and on the pounds of water removed/minute rate. Remember that these are a measure of a dryer's efficiency and productivity.

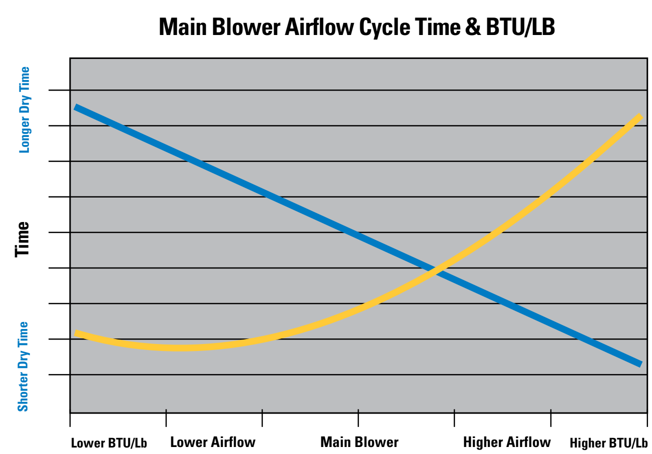


Figure 29 —Main blower airflow cycle time & BTU/LB

Lets take a minute to understand what this graph is trying to tell us. The horizontal axis denotes blower speed or air velocity. As you go farther to the right on the horizontal axis, you see an increase in blower speed and thus airflow. On the left vertical axis, total dryer cycle time is included. On the right vertical axis, total dryer BTU/lb of water removed rates are depicted. Now we can dive into what these numbers are trying to tell us.

First, it is evident that high airflow volume results in faster dry times (as denoted by the blue line) but at the sacrifice of lower energy efficiency (as denoted by the yellow line). Thus having a dryer with maximum airflow will theoretically increase your productivity, but it will also increase your energy bill.

On the other hand, reducing the airflow will certainly reduce your energy bill (as denoted by the yellow line), but your productivity rate from this dryer will not be very good (as denoted by the blue line). Now as a dryer manufacturer, we want to give you the best of both.

Sounds easy right?

Just pick the point where both lines cross each other! We all wish it were that easy. In theory, this might work, but in practice there is much more to determining the optimal airflow.

One of the first considerations when designing a dryer's airflow is to determine how to optimally mix the heated air by determining the type of burner or steam coil to use and where to position that burner or coil in the incoming air stream. This important first step will ultimately determine how that heated air is brought into the dryer vessel to perform the function of evaporation. There are a number of methods to include bringing air in from the top, sides, front and rear, or combinations of all four. Today's modern design tools allow engineers to model airflow and the application of heat throughout the system before they actual build the first prototype. Remember these tenants of airflow:

Air is compressible, air expands when heated, and air velocity helps convey away moisture.

Figures 30 & 31 show examples of how 3-D modeling can help engineers determine that optimal point to get both efficiency and productivity from their dryer.

Now the purpose of this previous discussion is not to make dryer design engineers out of the reader, but to help them understand that there are many factors that govern how airflow is applied to a dryer and no single way (like the crossover point on the curve) will work best for all types of designs.

Velocity

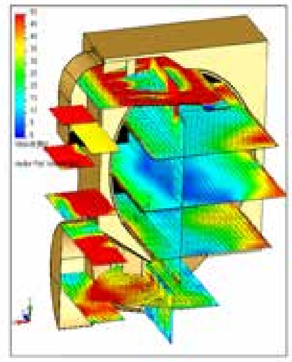


Figure 30

Flow Trajectory Plot

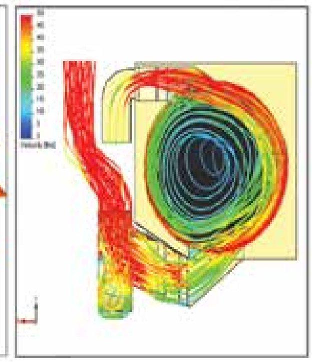


Figure 31

general rule of thumb can be derived from looking at the graph in figure 29. A higher rate of airflow, in general, is going to produce reduced efficiency and better productivity than a generally low airflow, which will produce an increased efficiency and reduced productivity. To obtain high airflows in an industrial dryer requires that the dryer be constructed of rigid weldments, as the forces applied to industrial dryers with high airflow can be quite considerable. As an example, the average vacuum generated in today's dryers can exceed 12 inches of water column. When this type of force is applied to many square inches of surface within the dryer, significant structure is required. For example, in a 300 pound dryer, this force can be over two thousand pounds of force. This is one reason why a dryer must be made with a heavy-duty superstructure. Dryers manufactured with light gauge material are not going to hold up to the rigors of industrial drying and remain reliable and air tight for many years of use.

In order to make the best use of optimal airflow and the heated air that it brings, the dryer must have a means of moving the goods through this heated airflow for the most efficient drying possible. To do this, the third piece of the Dry Pie^{SM} is needed.

Mechanical Action (Tumbling)

The mechanical action as defined within the Dry Pie[SM] is used for a much different reason than it was used for in the Wash Pie. If you remember, mechanical action needed for washing allows the goods to release soil so it can be suspended and removed by the surfactants used in the wash process.

Mechanical action in an industrial dryer is needed to ensure uniformly heated airflow is distributed on the goods during the drying process. Without any mechanical action, the goods would simply sit on the bottom of the dryer basket, impeding airflow, and thus impeding the removal of moisture. However, in a dryer, the mechanical action is not needed to drive moisture out of the goods, but to tumble the goods through the heated airstream allowing that air to pass through the fibers and take away the evaporated water.

So how is the optimal mechanical action determined within an industrial dryer, and should it be the same for all goods types?

This section will attempt to answer these questions and present the science behind the answer.

There are four design considerations used when determining the correct mechanical action for a given dryer size. First, the specific speed or RPM must be determined, which may be different for various goods types. Second, the basket diameter will play a key role, as will the third factor, basket volume relative to the rated load size to be used in the dryer. The forth factor is rib design and how those ribs are able to produce a smooth tumbling action in the airstream. Lets start this discussion by looking at the most important factor as it relates to efficiency, and that is volume as related to load size. Figure 32 is a graph showing what load size variation does to dryer efficiency based on a 300 – 350 pound rated dryer.

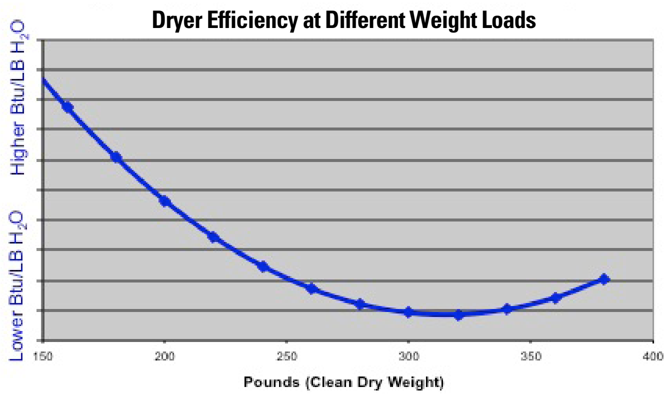


Figure 32—Dryer Efficiency at different weight loads

This graph represents probably the most misunderstood parameter of modern dryers today. In a world where bigger is better, and discussion of load factor reins, science can help us understand how to get the best energy efficiency possible given the volume of your dryer basket. As can be seen in Figure 32, as load weight increases toward rated load size for this dryer, efficiency steadily improves. As rated load size is exceeded, efficiency begins to fall off. This relationship holds for any type of dryer, no matter what the heat source or airflow. It represents the one single parameter that is the easiest to control in a laundry, yet the one parameter most overlooked or misunderstood. The key to getting the most efficiency out of your dryers begins in your soil sort area. If 310 lbs clean dry weight happens to be your dryer's "sweet spot" as shown in Figure 32, then you must determine what the correct soil weight is for each type of product going to your tunnel so that 310 lbs clean dry weight will be dried in this dryer. You also must ensure that your tunnel is sized correctly to give proper cleanliness at these load weights (in this case the tunnel size should be 150lb capacity with double cakes to the dryer). Running undersized loads because the rated load capacity of your tunnel is less than your dryer is a recipe for inefficiency and a guarantee that your energy bill will be much higher than necessary.

So how can you use this information to benchmark your dryers?

Remember, dryer basket volume is directly proportional to the energy efficiency of the dryer. Bigger isn't always better.

Benchmarking the "sweet spot" of your existing dryers is really quite easy, although some time must be dedicated to collecting the data. Benchmarking will help tell you if the dryer manufacturer did their homework when developing the clean dry weight rating for the dryer. If they rated it too low or too high, you aren't getting optimal efficiency or productivity from your purchase.

First, lets cover the terminology used when discussing performance related to dryers. Here is a list of three very important items and a description of each one:

* BTUs per pound of water removed (Energy Efficiency)

** Pounds of water removed per minute (Productivity)

These terms will be used extensively throughout the remaining dryer section and are terms that are key to developing sound measurements for any laundry to benchmark their dryer's efficiency and performance.

First, you must determine the rated load weight of your dryer. This is always shown in clean dry weight. Next, weigh a load of clean dry goods to this rated load weight. Run this load through your normal wash process to include the extraction step. Next, weigh the load after extraction and note the weight. This will give you the moisture content of that load, and thus, the extraction efficiency of your washer, batch press extractor, or centrifugal extractor.

Remember that it is always more efficient to remove moisture in your extraction process than in an industrial dryer!

Now, to complete this benchmarking exercise, you must have a meter on your dryer to measure the energy consumption needed to dry this test load. Once you have that installed, note the beginning reading on the meter before you put the load in the dryer. Load the dryer with this test load. The next critical data needed is the actual dry time. This is measured from when the burner ignites or the air and/or steam starts flowing through the steam coils and stops when the burner is extinguished or the air and/or steam stops flowing through the steam coils. It does not include the lint blowdown time, purge time, cool down time, or other "non-dry" events that may occur in your dryer before or after the actual dry cycle. Make sure you do not under dry or over dry this load as this will throw off your measurements. Dial in your dry formula before starting this exercise. Record the meter reading at the end of the dry cycle.

When the load is done, remove it from the dryer and weigh it one more time. This should equal the same clean dry weight you recorded prior to putting it into your wash process.

Now it is a simple matter of performing some calculations to determine the two key benchmarks of your dryer. First, convert your meter readings into BTUs. Typically gas meter readings are measured in cubic feet. Remember that 1 cubic foot = 1,000 BTUs unless you're using LPG, then use 1 cubic foot = 2,500 BTUs.

Subtract the clean dry weight of your load from the wet weight (recorded after the extraction process). This is the weight of the water that was removed during the drying process. Take the total BTUs consumed in your dry cycle (from your gas meter reading) and divide it by this total water weight. You now have the first of the key benchmark numbers. (BUT/LB)*

Next, take the total weight of the water in the load and divide it by the total dry time (in minutes). You now have the second benchmark number. (LB of HO/MIN)**

You can perform this exercise for a few loads under the rated load weight of your dryer and a few above the rated load weight to generate a curve similar to the one shown in Figure 32. Now you have a metric to monitor to ensure your dryer remains running at its peak performance characteristics.

We've spent some time discussing load weight and benchmarking, as this is an extremely important exercise the end user should perform to develop metrics for their dryers. However, it is not the only piece of the mechanical action puzzle.

The type of tumbling action that occurs inside the dryer basket is also very important to the efficiency numbers obtained in your benchmarking. The diameter of the basket in relation to the length (or depth) of the basket plays a key role. Long slender basket designs tend to reduce tumbling action as do short baskets with large diameters. These types of designs can also lead to tangled (roped) goods. The right ratio is a key design element used by today's engineers to get the most efficient tumbling action possible.

Basket ribs also play a significant role in tumbling action as they do in a washer. They are mainly used to lift the wet goods into the air stream at the beginning stage of the dry cycle. Ribs that are too large will compartmentalize the goods and reduce tumbling action, while ribs that are too small will not lift the wet goods into the air stream. As the goods become dryer, the ribs play less of a role and centrifugal force comes more into play.

Experimentation with different goods types shows that optimal airflow, and thus optimal drying happens when an almost perfect cylinder of goods tumbling around a hollow center occurs. To obtain this condition for various goods types with various moisture contents, variable basket speed can be employed. Having the optimum basket speed for each goods type can also help with efficiency. This is typically done using an inverter drive on the basket motor in conjunction with programmable speed within the dry formula or by automating this process for the user within the dryer controller.

In summary, like its cousin on the washer side, mechanical action plays a critical role in the efficiency of today's modern industrial dryers. It is an important component of the Dry Pie℠. That leaves only one piece left, and that is time.

Time

Last, but certainly not least is time. Unfortunately time is the one component that can cost the user both money (in fuel usage) and productivity (turns per hour). The shorter time needed to dry a load of goods, the less fuel used and the higher the turn ratio. However, time ties all the components together, as different types of textiles require different temperatures and mechanical action. These different requirements will dictate how much time it takes to complete the drying process for each particular textile type. Time also plays a key role in airflow as water must be allowed to begin to evaporate, and airflow must be given a chance to carry that moisture away from the processing environment.

Time seems to be the easiest of the pieces to use and understand, but it can also be the most costly in terms of your dryer's efficiency. Lets take a look at why that might be.

In order to get a given size load of goods dry, we've already seen that a heat source or temperature is needed to heat the airflow that is passed through the goods by means of mechanical action. The reader has also seen how benchmarking a dryer can provide key metrics when attempting to control costs generated while running the dryers. Remember that one important data point needed to calculate the BTU/lb of water removed and lbs of water removed/minute was the dry time. This is pretty straight forward as time is needed so the goods can interact with the other three elements of the Dry Pie℠ and allow water to evaporate.

Unfortunately, time is also the one piece of the Dry Pie℠ that is most abused at the sacrifice of using other types of technology available in modern dryers today. For the end user, it is easy to just add another couple minutes onto the dry time if they get a damp load, then to actually identify the root cause for that damp load and resolve it. It is also a good bet that the additional time added would not be removed once that root cause is determined or conditions change that no longer require the additional time anymore. That additional time means more fuel is being consumed and fewer goods per hour are being sent to the finishing department. This lowers the overall efficiency and productivity of the dryer. Overdrying can also lead to damaged textiles and shortened textile service life.

Many variables can impact dry time to include inside and outside temperature and humidity, temperature of the goods when they go into the dryer, moisture content of the goods from load to load, and many other variables that can change the dry time needed with almost every load. Remember that for optimal drying, the user should target a moisture remaining number of between 2% - 5%. Doing this consistently with time alone is almost impossible.

So why do most users rely on time?

Simple…it's easy to understand the relationship that more time equals more drying.

But is it really the best method to use?....NO!

The following discussion looks at other methods that modern industrial dryers employ to provide a more economical means of drying goods without using a timer like the old dryers of the past.

Emerging Technologies

During the discussion regarding the science behind temperature, a short overview was presented on the use of differential temperature. Most modern industrial dryers today offer differential temperature setpoints as an alternative to using time in the dry formula. The science behind using differential temperature as an alternative can be seen in Figure 33.

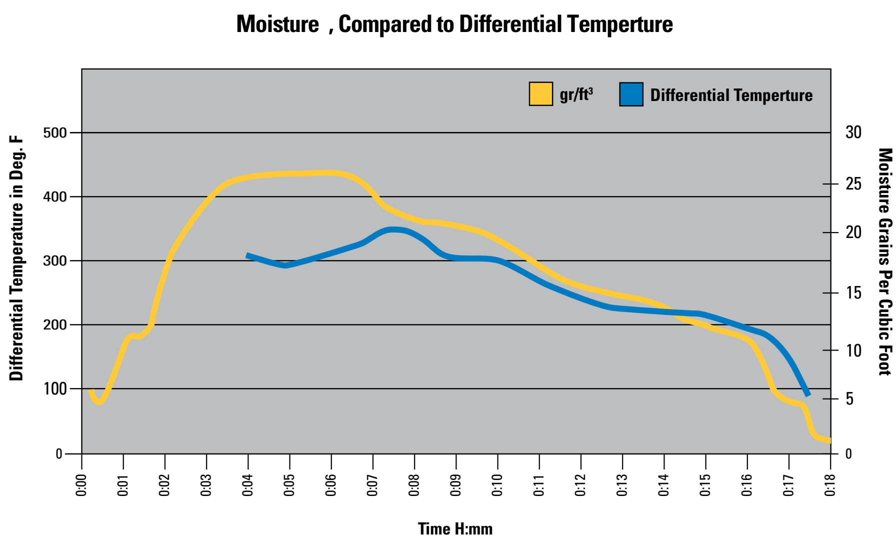


Figure 33—Moisture gr/ft³, compared to differential temperture

Differential Temperature

Differential temperature technology use can be explained by examining how the wet bulb/dry bulb thermometer works. In this analogy, the dry bulb is the inlet temperature and the wet bulb temperature represents the exhaust temperature in the dryer. The measured exhaust temperature will always be lower than the inlet temperature because of the evaporative cooling affect on the exhaust air stream. As the load gets closer to having the ideal moisture content (between 2% - 5%), the two temperatures become closer to each other. Figure 33 graphs humidity readings in the exhaust of the dryer and the differential temperature. Comparing the slope of the humidity curve with the slope of the differential temperature curve during the drying portion of the cycle shows that both measurements track a very similar profile. Similar to clock timers, some adjustments must be made for large swings in outside conditions, especially during seasonal changes.

The important note is that differential temperature is a much closer representation of the actual moisture content being removed at a given time and will always produce more consistent results than the use of time alone.

As we examine differential temperature and the close correlation to moisture removal, it may become apparent to the reader that using a moisture sensor would be the best of all possible methods to guarantee that 2% - 5% moisture content in the finished load of goods. Sounds good, but there are some pitfalls in moisture sensing technology that the reader should be aware of.

Moisture Sensors

Moisture sensing technology has been in use for a number of years, especially in residential dryers. It has been introduced in large industrial dryers, but has not been generally adopted. There are a number of reasons, and those will be described in this discussion.

First, a short understanding of the different types of moisture sensors is in order. Moisture sensors can be obtained in several different types. The two most common are resistive and capacitive. There are also some manufacturers that have attempted to use conductivity sensors to measure moisture inside the industrial dryers. To study the viability of moisture sensors, an experiment was conducted using a moisture sensor (capacitive type) mounted in the exhaust air stream. This generated the graph shown in Figure 34. Multiple loads with different load weights were washed, extracted, weighed and then dried until the moisture sensor determined the moisture level was 10 grams per cubic foot. The load was then weighed again to determine the actual moisture remaining in the load.

The results of this experiment were fairly conclusive. As load weight varied, so did the moisture content of the actual load. Most readers may have experience using moisture sensors on their residential dryers and had damp loads as a result. The same principle holds true for large industrial dryers using just moisture sensing for dryness determination. As load weight varies from load to load, so will moisture content and thus, the potential for a damp load to be produced increases. Obviously this is disruptive to the process as this load must either be dried again, or processed outside the normal methods for that laundry adding unanticipated cost for the user.

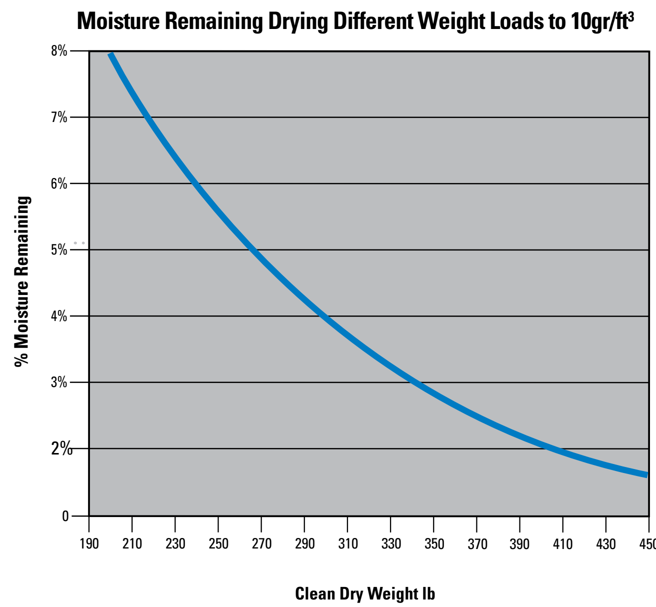


Figure 34 —Moisture remaining drying different weight loads to 10 gr/ft³

So why does this variance happen with load size variation?

Lets look at a simple example:

Imagine a dryer with 1,000 hand towels with each towel having one drop of water in it. Compare that to 10 hand towels with each towel having 100 drops of water in them. As heat is applied to each load, the moisture-sensing device will read a similar value. However, when you weigh the goods at the end of identical length dry cycles, the percent of the water remaining in the goods will be different. The reason is that the moisture sensor is measuring the moisture in the air stream versus the actual moisture remaining in the goods.

The other main downside of moisture sensors is the contamination that dryer air streams typically carry. Lint, sand, and other particulate can have devastating consequences on the life span of moisture sensors in an industrial dryer application.

Infrared Technology

Another method used in many industrial dryers today is infrared technology. Infrared technology is a very viable means to detect temperature (actually emissivity) and thus calculate the moisture remaining using the dryer controller. The limitation on the application of infrared sensors is the locations available to sense the goods inside the dryer basket as the dry cycle progresses. As the temperature of the tumbling goods changes, the infrared sensor can read those changes. The key to successful implementation and repeatable performance is that the entire load must be sampled to ensure it is completely dry (or has the 2% - 5% moisture remaining in it). This limitation has proven somewhat challenging to dryer manufacturers as looking at a large enough sample to represent the condition of the entire load is very difficult to do. The sensor may be able to tell the outer portion of the load is dry or tell the inner portion is dry, but the beam spread and interpolation of that spread is not presently reliable enough to detect dry conditions repeatedly load after load. Varying emissivity levels of different material inside the dryer also presents a challenge for infrared sensors. However, as technology changes and sensors become smaller and easier to locate within the dryer basket itself, the technology holds promise.

Heat Recovery Technology

The previous sections have focused on the science behind drying and the Dry Pie^{SM}. As the reader can see, many factors contribute to each piece of that pie. One factor becoming more commonly used is heat recovery. It is certainly not difficult science to understand. Waste energy in the form of heated air is being discharged to the outside. If that energy can be captured and reused to heat the incoming air, efficiency should be gained.

Heat exchange technology is certainly not new, but as energy costs continue to rise, new designs are being promoted with new savings claims being made. There really are two distinct types of heat exchange technology. The first is really heat recirculation. The science here is to take the waste air stream and reroute some or all of it back into the intake air stream.

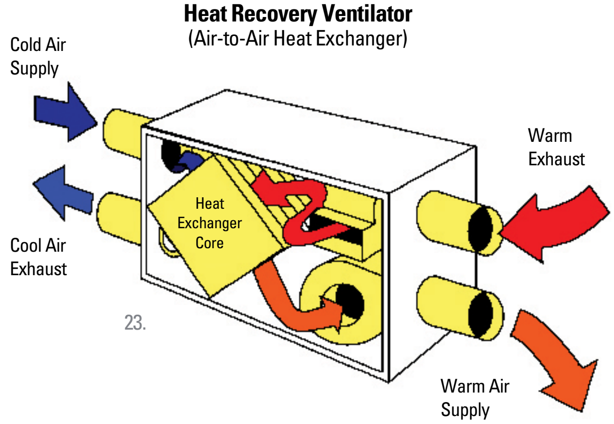
Sounds like a winner right?

Well think about this for a moment and go back to the fundamentals of drying. The purpose of a dryer is to remove (or evaporate) moisture from a load of textiles. The air stream exiting the dryer during this process contains that moisture. It seems intuitive that putting this high moisture content air back into the dryer would be somewhat counter to the stated objective. If you're thinking this, you're partially right.

However, remember that 40% - 60% of the moisture is evaporated off during the first 5 minutes or so of the dry cycle, and recirculation begins to make more sense. What if we can predict the moisture content of the air stream and, using automatically controlled dampers; redirect that hot air back into the inlet air stream after the moisture content has reduced to an acceptable level where it benefits the efficiency instead of hurting it? This is exactly what some manufacturers have done and modest gains in efficiency have been seen. These gains range from 3% - 10% depending on the temperature of the incoming air and the moisture content of the recirculated air when it is redirected back into the intake.

The other method is true heat exchange technology. This involves passing the heated waste air stream over

Heat Recovery Ventilator
(Air-to-Air Heat Exchanger)



23.

a median that then is used to pass the incoming air through to pre-heat it. Again, the effectiveness of this depends on the temperature of the incoming air to begin with. The gains with this type of technology are slightly higher than recirculation and range from 10% - 15%. Claims of significantly higher efficiency gains have been made; however, when tested using the benchmarking procedures described earlier, these claims have not materialized. Also, this technology brings with it some hidden costs that often aren't fully explained to the end user. These costs come in the form of increased preventative maintenance.

Remember from the previous discussions that the waste air stream of an industrial dryer contains significant contamination in the form of lint, sand, and other types of debris. When this air stream is passed through a perforated plate, coil, or other median, that debris is trapped. If not maintained, this debris will ultimately block the flow of air, leading to significant problems with the dryer to include excessive high temperature alarms and possibly, in severe cases, fire. This is not to say there isn't a benefit to the technology, but it is important for this discussion that the reader understand the added maintenance that comes with it.

So is that heat reclamation system really saving you money?

To calculate this, we'll run the numbers for a 500lb clean dry weight rated dryer. We'll also assume a 10% energy savings from the heat reclamation system. Assume that the dryer is consuming 1,800 BTU/lb of H2O removed, must dry goods with 50% moisture retention (or 250 lbs of H2O), and is being turned over 3 times/hour. Last, we'll assume the plant operates 1 shift/day, 5 days per week or 2,080 hours/year and the cost of NG per therm is $0.50/therm.

Here's the calculation of the savings per dryer:

10% x 1,800 BTU/lbs H2O x 250 lbs H2O/load x 3 loads/hour x 2,080 hours/year x 1 therm/100,000 BTUs x $0.50/therm = $1,404/year or ~$0.68/hour

The readers must ask themselves if this savings per year is worth the additional maintenance that is inherent in the heat reclamation system to begin with. How many hours per year will you dedicate to maintaining this system? How much downtime or lost productivity will you experience due to exhaust temperature alarms due to lint build up? The homework needs to be done before buying into the actual savings.

There is one additional type of heat exchange technology that is fairly common. That technology is the use of **coaxial ductwork**. Again, from the previous discussion on fundamentals, a dryer must have air supplied to it and that air is then discharged from it to the outside. If the duct bringing the hot air out surrounded the duct bringing fresh air in, the incoming air will be heated by that waste air discharge at a rate of approximately 1 degree F per linear foot of duct run. So a 20-foot coaxial duct run from the dryer to the outside would increase the temperature of the incoming air approximately 20 degrees F.

What would this mean in energy savings?

Well like the caveat noted in the other types of reclamation, the temperature of the incoming air would play a major role. On the average, coaxial duct runs greater than 20 feet with an average inlet air temperature of 50 degrees, would see a 2% - 3% increase in efficiency increasing as the length of duct run increases. Coaxial duct also eliminates the maintenance problem with debris in the exhaust air stream, as there are no perforated plates, coils or other heat exchange media to catch it.

Lint Collection

The last portion of this section is a brief look at the various types of lint collection systems available in today's industrial dryers. There are basically three types: internal, external dry, and external wet. Lint collection is very important, as discharging lint into the environment is not desired. One point to remember with dry-type lint collection systems, whether internal or external, is that they are only approximately 90% effective in stopping lint. A wet-type lint collector will stop up to 100% of the lint, but at a significantly higher cost. Lets take a look at each and the fundamentals of how they work.

Internal Lint Collection:

This type of lint collector is built into the dryer and the exhaust air stream is passed through screens to filter out lint. Some internal lint collectors have automatic blowdown after each dry cycle and some are completely manual requiring operators to clean them out throughout the production shift. Some automated internal lint collectors also have an external vacuum unit connected to remove the lint for easy disposal removing the requirement to clean the internal collector periodically. Internal lint collectors will protect components downstream like the dryer blower wheel from debris, which could cause damage or at minimum, add a preventative maintenance step to clean the lint from the wheel so it doesn't become unbalanced. Internal lint collectors are typically less expensive than both dry and wet external collectors.

External Lint Collection

This type of lint collector is typically mounted downstream of the exhaust air stream past the dryer's blower motor. It can be mounted to the dryer itself or mounted separately from the dryer. The external lint collector is most often automated and conducts a blowdown either during the dry cycle or when static pressure increases beyond a specified threshold. External lint collectors typically add footprint to the installation of the dryer and require a fire protection system separate from the dryer's. They are usually sized so that cleanout can be conducted once or twice a day. External collectors are more expensive both in initial cost and in some cases add cost for installation. Note: External collectors typically increase the cost of the duct work and can consume a great deal of floor space.

Wet Lint Collectors:

As the name implies, wet-type lint collectors use water to capture lint from the air stream. They are always mounted externally to the dryer, usually on the roof. Water is sprayed into a chamber that the exhaust air stream is passing through. Lint becomes quickly saturated by the water and falls out of the air stream. Wet collectors are very effective in removing lint (up to 100%), but also are extremely costly both in the up front cost and installation cost. They are also not really suited for cold climate installs unless they are installed inside the facility.

The last section of this discussion on dryers will focus on some common preventative maintenance that needs to be done to keep your dryer running as efficiently as possible.

Preventative Maintenance

The first area to focus on is the airflow. As this document has shown, airflow is one of the four critical elements of the Dry Pie^{SM} and any restrictions that impede airflow need to be dealt with quickly or the efficiency of the dryer will be compromised. Also, if airflow restrictions are neglected and become serious enough, a dryer fire can occur from overheating.

So where do you start when it comes to ensuring good airflow?

Lets start with installation and discuss the dryer's ductwork.

First, before looking at the dryer itself, check the ductwork connected to the dryer starting from the roof. If you find screens attached to the entrance of the inlet or exhaust duct (usually installed to keep animals/birds out), remove them. Screens act as a lint trap on the exhaust duct and will quickly become clogged and restrict airflow. If you can't remove them, ensure that you setup a daily cleaning routine.

Unfortunately, if your ductwork is already installed, your airflow may be restricted because it was undersized or contains too many bends in the run to the dryer. This creates high static pressure and makes it difficult to pull air through the dryer. High static pressure can cause structural damage to the dryer, cause overheating problems, and if serious enough, can cause a dryer fire. If you're experiencing these types of problems and believe they are coming from poor ductwork, consult either the manufacturer or the company that installed the ductwork for recommendations on how to improve it.

The next area to check is the combustion airflow assuming the dryer is using NG or LPG as a fuel source (this section would not apply to a dryer using steam as a fuel source). NG and LPG burn very cleanly, but if the airflow to the burner is restricted, serious overheating problems up to and including a dryer fire can occur. Most dryers have a combustion air filter. Check the operations/ maintenance manual that came with the dryer. This air filter must be checked on a daily basis as lint will easily clog it and cause poor combustion. This is a very easy PM to do and one of the most critical in terms of efficiency of the dryer. Another way to check for poor combustion airflow is to watch the flame during the dry cycle. The flame should be bluish white and uniform under normal conditions. If the flame is ragged and yellowish, there is a combustion airflow problem and it should be dealt with as soon as practical.

Remember the discussion on airflow from the beginning of the dryer section. Air is pulled through the dryer using a blower fan. The key to good airflow is to ensure there are no restrictions in its path through the dryer. The next area to check after the ductwork is the basket. Industrial dryer baskets are typically made up of panels. Some manufacturers provide removable panels. These panels are perforated to allow the air to exit the basket. Because many laundries have poor soil sort practices, items such as plastic bags, plastic soda bottles, heart monitor stickers, and everything in between end up in wash loads.

Ultimately this contamination ends up in the dryer where it melts and becomes embedded in the dryer basket perforations. If not removed, it will significantly impact airflow and lead to poor dryer performance. As mentioned earlier, many manufacturers supply removable panels. Purchasing a couple extras will allow for a rotation schedule giving maintenance personnel the opportunity to clean the panels offline without interrupting production. The clean panels can be put back in at the next scheduled PM. Most manufacturers also provide either a Teflon or Ceramic coated panel that helps prevent plastic debris from sticking to begin with. A better solution to this problem is to attack it at the source – Soil Sort.

Another impediment to airflow as it exits the dryer is the lint screens. Whether the dryer has an internal or external lint collector, dirty, clogged lint screens are a common source of airflow restriction. Ensure proper PMs are established to check the lint screens daily to ensure they are blowing down (if automated) or being cleaned (if manual) correctly and as specified.

The last item to check that can really impact dryer efficiency is air leaks. All dryers use different types of seals to prevent hot air from leaking from the basket area and to prevent ambient air from being pulled into the baskets. These seals may be located on the inside of doors, faceplates, inside the shell up against the outside of the basket, and many other places depending on make. Consult the operations and maintenance manual to locate all seals for your particular dryer and be sure that seals are checked on a routine basis and replaced as needed. A few dollars spent on seals will go a long way in keeping your dryer running at peak efficiency.

As a wrap up to the drying process discussion, the following section is a brief overview on the most common types of industrial dryers used in laundry industry and how they are loaded and unload in both manual and automated situations.

Dryer Types

This document has spent a fair amount of time describing the drying process and the science behind it. What the document hasn't done to this point is describe the types of dryers that are commonly used in today's laundries.

In general, there is only one type of dryer used in tunnel systems today. This type can be used in both a tunnel system and a washer extractor system. These are referred to as Pass-Thru Dryers. Most all tunnel system dryers are of the Pass-Thru type. Some may tilt to load and unload and others are stationary using the dryer's blower to assist in unloading and reducing the necessity for compressed air or hydraulics. Some manufacturers offer dryers that can be put in pairs side-by-side to save space over the conventional type Pass-Thru dryers, which must have space left between each machine. These side-by-side paired dryers must have space left between the pairs (usually 36" – 42" depending on local code requirements). One manufacturer offers Pass Thru tunnel system dryers that can be put in a continuous side-by-side configuration without the space left between pairs, as others must have. This is because the electrical control boxes are not located on the side of the dryers, but are located on the back discharge chute allowing for easy access from the back side of the unload conveyor. Dryer controls are another key aspect and difference between various manufacturers.

When dryers are placed in a tunnel system, they are controlled by different control schemes. Some manufacturers opt to control an entire bank of dryers from a central control platform that is usually located within easy access by the operator outside the main dryer alley. The advantages of this type of system are it allows manipulation of formulas, functions and other aspects of the dryers from one point. It makes changes on one dryer easy to transfer to the others controlled by the central control system. Unfortunately the advantages tend to be outweighed by the disadvantage of such a system. The failure of this central control system creates a situation where the entire dryer bank is rendered non-operational effectively shutting the tunnel system down.

Other manufacturers offer individual controls for each dryer in the system and they usually can be controlled from a central point. However, the central control system can become non-operational and the dryer bank continues to function. Most manufacturers locate the controls on the side or front of the dryers necessitating access into the dryer alley to manipulate/repair the individual dryer control. One manufacturer offers this individual control platform on the rear discharge chute accessible from the backside of the unload conveyor thus allowing control changes/manipulation/repair while remaining outside the dryer alley. From a safety standpoint, entering the dryer alley usually requires shutting down the shuttle/loading system via an entrance interlock. This can have negative impacts on productivity while the dryer control is being manipulated or repaired.

Tunnel system dryers come in different load size ratings. These load sizes are almost always specified in clean dry weight. When selecting dryers for a tunnel system, the user must ensure that the dryers are sized for the standard load weight being run in the batch tunnel washer. This brings us to another key aspect of selecting the right dryers. Tunnel systems are typically loaded by a shuttle that carries the pressed goods (cakes) from the batch press extractor to the dryers. For correct

sizing, the laundry must determine if they are going to load single or double batches from the press. This decision is usually a function of batch sizing at the front end or soil sort area. If there are insufficient quantities of each good type to allow loading the tunnel with double batches of like goods, then sizing the dryers for single batch tunnel loads is called for. On the other hand, if sufficient quantities of goods do exist to ensure each good is run in double batches through the tunnel, sizing the dryers for the double batch weight would be appropriate. Getting this sizing right up front is critical in ensuring the most efficient system possible. The other critical area is determining how many dryers are needed for a given tunnel system. This is probably the most overlooked aspect when a laundry is designing a new tunnel system and dryers are the most likely piece of equipment to be cut out when costs are tight.

When tunnel systems are being designed, many start with the size of the tunnel and the transfer time they plan to run basing this decision on planned yearly production and goods mix. They overlook key aspects like the amount of moisture retention those transfer times will dictate in the batch press extractors and what that moisture retention will mean in terms of drying capacity needed. Jim Curiale wrote a great article in the February 2009 addition of Textile Rental that describes this process in detail. The intent here is not to republish Jim's article or detail out the tunnel design process. We'll leave it to the reader to review that article in depth, as it is an invaluable tool when designing/sizing tunnel systems.

The last area we'll cover are the typical material handling systems available today to facilitate the loading and unloading process for batch tunnel system dryers.

Material Handling for Tunnel System Dryers

Batch tunnel system dryers can be loaded a number of different ways. The most common is with a Nesting Shuttle. This shuttle allows two cakes from a press extractor to be loaded and brought to one of the system dryers for drying. This process is completed automatically.

Another method gaining popularity is taking the cake from the press extractor up into an overhead sling bag where it is placed into a clean storage cue. Bags are automatically called from this cue when a dryer becomes ready to load. This layout provides a buffer for the tunnel/press so that in a situation that causes all the dryers to be busy in dry cycles, the tunnel/press will not come to a standstill, which occurs in a normal shuttle configuration. A typical layout in this type of scenario is pairs of dryers located in two lines with Cross Conveyors tying a dryer on one side of the dryer alley to the dryer on the other side. The bag comes from the storage area and positions itself over the cross conveyor, drops, and is conveyed into the waiting dryer. Each conveyor can load two dryers, but not at the same time. The downside is if a conveyor has mechanical issues, two dryers are taken out of service until the conveyor is fixed. One manufacturer has patented a chute loaded dryer that removes the need for the cross conveyor. These chute loaded dryers allow the sling bag to open and drop the goods directly into the dryer, removing the conveyance time with the cross conveyors and the liability of losing a cross conveyor and thus two dryers. This solution also provides greater design flexibility when laying out the facility.

This is only a brief examination on types of dryers and methods for loading them. As the reader can see, in batch tunnel systems, conveyance devices or clean storage systems are extremely important to transport the goods from the wet side to the dryers. The next section will examine the different types of unloading options available for batch tunnel systems dryers.

Dryer Unloading Options

The last area this section will take a look at is the dryer unload process. Most dryers used in a tunnel system unload to an unload conveyor, although a few do unload directly to a cart. Unloading to a cart is very inefficient, but may be the only method given existing floor space. Let's focus on the unload conveyor as there are a couple different scenarios that can be used.

In a typical automated tunnel system, a conveyor is run behind the dryers. Pass-through dryers are utilized (see previous section on dryer types). When the dryer has completed the cool down cycle and becomes ready to unload, a rear door opens; the dryer tilts back, and goods are deposited onto the conveyor. This is now a good spot to discuss the types of configurations that can be employed on these unload conveyors.

There are four typical types of configurations used for an unload conveyor. The first is pretty straightforward. The flat unload conveyor is configured with one additional incline conveyor on one end. The goods are transported to the top of this incline conveyor and stop. When an operator has a cart in position, the goods are manually jogged off the incline and into a waiting cart. Again, this is fairly labor intensive, but in many plants, space and/or height restrictions prevent a more automated solution.

The second configuration is a simple variation of the first. A second incline conveyor is attached to the opposite end from the first. The system can be programmed to send goods in either direction. This can be particularly useful when the finishing area of the plant on one end handles a specific type of goods and the finishing area on the other handles a different type. Again, if goods are manually unloaded into carts, this type of operation can be extremely inefficient. If goods are not unloaded in a timely manner, the unload conveyor can become backed up and not allow waiting dryers to unload. This will then cause backup on the front end of the process causing a lot of wasted productive time for the entire wash system. This is a scenario where a clean-side rail storage system with either conveyor or chute loaded dryers can play a big role in keeping the tunnel system productive.

A better option if the facility design will allow it, is the use of automated (or manual) take-away slings. In this type of system, the goods travel up the incline conveyor and are dropped into a sling bag. The sling bag is then raised and put into a finishing cue to be processed as needed by the finishing department. The limitation to this type of system is total weight the sling system can handle. If unloading more than ~300 – 350 lbs, an operator must be present to ensure the sling bags are not overloaded. This type of system can be utilized with a dual incline system as well.

A third option for an unload conveyor system is use of a vertical drop to either a waiting sling bag (or cart). In this situation, the goods are conveyed to one end of the flat conveyor and drop through an opening into a sling bag (or cart). This type of system would also most likely need an operator to monitor it to ensure carts are in place or that bags are not overloaded (for system load weights over ~ 300 - 350 lbs). However, it is a very viable option, especially for dryers that are located on a 2nd floor or mezzanine. This may be a good option for systems utilizing a vacuum or chute loading system for the dryers when they are located above the wash alley.

This section has hopefully given you an overview of the different types of conveyance devices that are available for a batch tunnel system. There are many variations of these types of devices that were not covered here, but all involve use of conveyors, shuttles, and/or sling systems. Moving goods from one process to the next is often an area overlooked in plant design and layout. Make sure you take the time to study how your goods will travel from one process to the next as a poor design can cause significant productivity impacts on your overall wash and dry processes.

In conclusion, dryers are an integral part of today's laundries, but they are one of the largest consumers of energy costs and can be a limitation on production rates. Understanding the fundamentals and science behind the drying process coupled with good preventative maintenance will ensure your dryer performs efficiently and effectively for many years of service.

Appendix 1—Technology Comparison Table

	Transfer Method			Shell Construction		Counterflow Process		Drive Configuration	
	Bottom Open Helicoid	Bottom Archimedean Screw	Top	Single	Double	Direct	Indirect	Friction	Chain Around Perimeter
Pros:	Large open area between chambers	Smooth flow of goods and water between chambers	Less water transferred with goods for improved rinsing	Robust weldment with no moving parts	Chambers can be separate operations	Forces counterflow through goods matrix		No auto greasers or oilers	Single motor for drive
	Smooth flow of goods and water between chambers		No axial movement of goods during wash cycle closely simulating conventional washers	External seals easy to access	More bath exchanges possible to remove unwanted process water	More efficient rinsing		Easier drive or component replacement	
	No axial movement of goods during wash cycle closely simulating conventional washers				Easier for chemistry sampling			Multiple motors for drive allows operation when one motor or gearbox fails	
					More flexible for processing colored goods mix				
Cons:	None	Less open area due to center shaft and more propensity for goods jamming and roping	Less water transferred with goods causes high concentration spikes	Less flexibility for machine setup with fixed zones	Internal seals difficult to change and to determine if there are failures		Paths to by pass goods matrix are possible		Automatic greaser or oiler
		Axial movement of goods during wash cycle making less effective rib contact and mechanical action	High propensity for plugging and roping	Machine needs to be placed in standby for sampling	Long-term wear and potential component failure due to modular design		Less efficient rinsing		Major maintenance for drive and/or chain replacement
			More sensitive to water level effects on transfer of goods	Need to have empty pockets between colored goods and effects process time	Modular design can present a problem for movement and relocation of machine				

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