INFORMATION

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TECHNOLOGICAL BACKGROUND OF CONDITIONING

INTRODUCTION

WELKER as first manufacturer of steaming and conditioning machines since 1941 has set the basics of the conditioning process. This paper highlights important aspects of yarn conditioning processes with special regards to the physical capabilities and limitations. Knowledge of the fundamentals allows to find the optimum parameters to ensure the best improvement of the yarn quality in downstream processing.

THERMODYNAMICS

In the conditioning process a given quantity of m_Y [kg] of yarn is exposed to an atmosphere of saturated steam with a temperature of T_S [°C]. Yarn temperature T_Y is equal to mill temperature.

At this point it is important to highlight that all conditioning machines, regardless of its brand, work with saturated steam as medium for better penetration and condensation inside the yarn bobbins. Therefore, any statement trying to show differences of saturation such as “direct” or “indirect” steam, are technical nonsense.

Each yarn material is characterized by a specific heat capacity c_Y [kJ / kg k]. For cotton the constant is 1,38 kJ /kg k (Table 1)

Yarn material	***c [kJ / kg k]***
Cotton	*1,34*
Wool	*1,38*
Polyester	*1,38*
Polyamide	*1,89*

Table 1: specific heat capacity of different yarns

During the conditioning process the yarn is heated up from mill temperature to the set temperature of the process. The required heat is provided by steam which releases energy in contact with cold yarn when changing from vapour to liquid condensate. The heat energy taken by the yarn equals the heat energy provided by condensing steam. The following formula determines the transferred heat energy:

Heat absorbed by the yarn:

$$Q_Y = m_Y \times c_Y \times (T_S - T_Y)$$

Heat provided by the steam:

$$Q_S = m_S \times r$$

The weight increase of yarn during conditioning corresponds to the quantity of steam m_S which is condensing on the yarn. By equalling equation I. and II., the maximum amount of steam can be calculated as follows:

$$Q_Y = Q_S$$

$$m_Y \times c_Y \times (T_S - T_Y) = m_S \times r$$

$$m_S = \frac{m_Y \times c_Y \times (T_S - T_Y)}{r}$$

r = heat of vaporisation [kJ/kg] as per table 2

In terms of percentage the max. possible theoretic weight increase is:

$$W\ [\%] = \frac{c_Y \times (T_S - T_Y)}{r} \times 100$$

The only variable in this equation is the temperature of steam. The equation also shows that weight increase is only determined by temperature difference between yarn. Because only m_s [kg] of condensate are available for the absorption by the yarn, the weight increase in any conditioning process is limited to W [%] temperature and steam temperature.

Example:

Material	*Cotton*
c	*1,34 kJ/kgk (Table 1)*
Yarn temperature T_Y	*28°C*
Steam Temperature T_S	*65°C*
r	*2340 kJ/kgk (Table 2)*

$$W_{max} = \frac{1{,}34 \times (65 - 28)}{2340} \times 100 = \underline{2{,}2\ \%}$$

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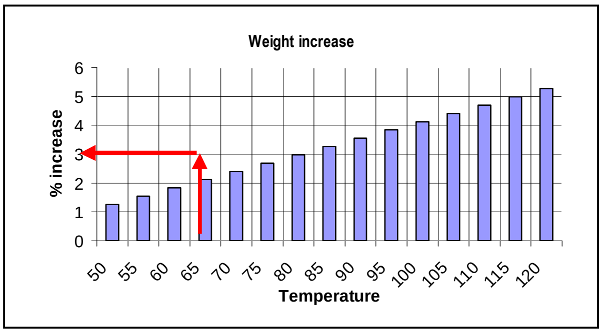
INFORMATION

TECHNOLOGICAL BACKGROUND OF CONDITIONING



HEAT TRANSFER IN VACUUM

Next to the steam temperature the vacuum in the process has strong influence on moisture increase. Vacuum is important for

- Heat transfer
- Steam atmosphere
- Steam penetration

HEAT TRANSFER

The condensation of saturated steam on yarn surface is governed by the general principles of heat transfer. Consequently, it is influenced by the presence of inert gases (like air) in the process.

If too much of air is absorbed at the fibre surface, there will be formed a barrier of molecules between steam and yarn. Therefore, the condensation efficiency would be reduced. In order to reduce this phenomenon to a minimum, it is necessary to create a vacuum ambient as high as possible.

STEAM ATMOSPHERE

Yarn conditioning requires a low temperature atmosphere of saturated steam. The relation between vacuum and steam temperature is given in steam tables (table 2).

Therefore, any machine operating at 90% vacuum will ensure a treatment starting at 45,84°C steaming/ conditioning temperature. Consequently, any machine operating at 60,0°C will have a vacuum of –80,0% or 200 mbar a.

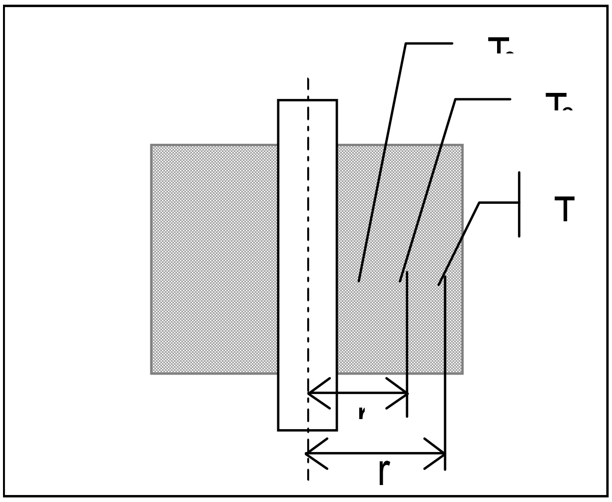
Pressure / Vacuum [mbar a] (-% Vacuum)	*Temperature [°C]*	*Heat of vaporisation [kJ/kg]*
100 (-90%)	*45,84*	*2393*
200 (-80%)	*60,09*	*2358*
300 (-70%)	*69,13*	*2336*
400 (-60%)	*75,89*	*2319*
500 (-50%)	*81,35*	*2305*
600 (-40%)	*85,96*	*2294*
700 (-30%)	*89,96*	*2283*
800 (-20%)	*93,51*	*2274*
900 (-10%)	*96,71*	*2266*
1000 (0,0%)	*99,63*	*2258*

Table 2. Steam table (VDI Wasserdampftafeln 7. Ausgabe 1968)

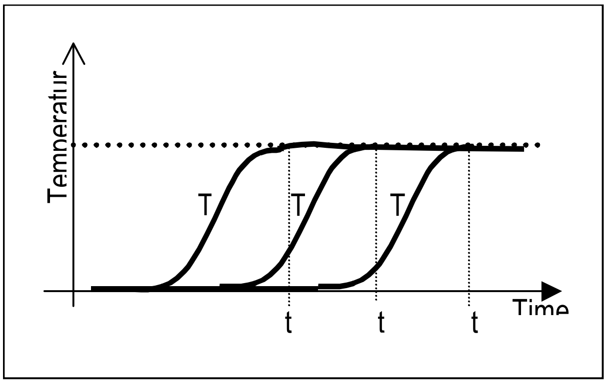
STEAM PENETRATION

During the vacuum conditioning process the "condensation area" always moves from outside to the inner layers of the yarn bobbins. Speed and intensity of this progressive condensation process are determined by the vacuum level.

In a series of trials the temperatures inside cylindrical bobbins were taken during the steaming process at different positions, as shown in the following picture:



TECHNOLOGICAL BACKGROUND OF CONDITIONING



Temperature curves: speed of the condensation zone

The speed of the condensation zone is:

$$v_K = \frac{r_n - r_{(n-1)}}{t_n - t_{(n-1)}}$$

The trials in the tests showed an average speed of approx. **4,5 mm/ min** at 95% vacuum (50 mbar abs.).

Example:
Outside bobbin diameter: 280 mm
Tube diameter: 40 mm

$$t = \frac{(280-40)\text{mm} / 2}{4,5 \text{ mm / min}} = \underline{26,66 \text{ min}}$$

After 26,6 minutes the bobbin is completely heated to steam temperature. Therefore, the steaming time in the conditioning process must be set at least to 26,6 minutes.

TEMPERATURE BALANCE

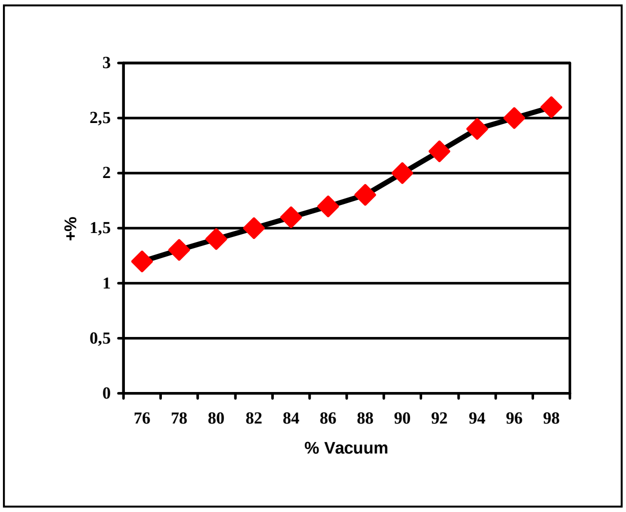
As long as there is a difference between the heated steam and the cooler yarn, the process will continue. If there is no difference anymore between yarn layers and steam, the condensation will come to a stop and no further weight increase takes place, creating the "balance of temperatures".

IMPORTANCE OF VACUUM LEVEL

The conditioning time depends on the package (cone-) diameter. The bigger the cones, the longer the conditioning time. Consequently, the vacuum level has utmost influence on steam penetration, uniformity of the treatment (quality) and the actual weight increase.

It is quite obvious that a hard wound bobbin of higher weight with a bigger diameter demands more vacuum than a smaller bobbin with less weight. In order to ensure a even distribution of moisture inside the bobbins regardless of its configuration and weight, the vacuum level should be around 95 % (50 mbar).

Equally, the higher the vacuum on a given bobbin, the higher the moisture penetration. The graph below shows the effect of vacuum in a CONDIBOX conditioning machine. The weight increase was of cotton yarn was taken at different vacuum levels:



Yarn temperature for trial	*24°C*
Steam temperature	*65°C*
Conditioning time	*25 minutes*
Cone diameter:	*210 mm*
Cone weight .	*1,89 kg*
Machine type:	*CONDIBOX*

INFORMATION

TECHNOLOGICAL BACKGROUND OF CONDITIONING

SECOND VACUUM CYCLE

Vacuum costs money. It costs energy and water if machines are not equipped with **WELKER BLUE LINE** technology.

Moreover, with bobbin weights above 2,6 kg and/ or diameters above 250 mm, **plants should consider to make a second vacuum to make sure steam penetration has been well done.**

This procedure is a physical phenomenon well known in literature and increases the penetration effect of saturated steam in deeper layers of the products.

WAXED YARNS

As shown before, the weight increase *only* depends on the temperature difference between steam and yarn ($T_S - T_Y$) and vacuum. Increase of steam temperature will increase the weight.

However, in case of waxed yarns the steam temperature is limited to the wax melting point. Steam temperatures exceeding the melting point will cause the wax particles to melt. Melting wax penetrates into the yarn and disappears, causing higher friction in circular knitting. Most of the wax melting points range between 55 and 65°C. Users shall request indication of the wax meting point from their wax suppliers.

COOLING AFTER CONDITIONING

The standard conditioning temperature is set to be 65°C.
Theoretically, increasing the temperature to e.g. 98 °C *initially* would create a higher weight increase. The weight raises in line with the temperature.

Example:

Material	*Cotton*
c	*1,34 kJ/kgk (Table 1)*
Yarn temperature T_Y	*28°C*
Steam Temperature T_S	*100°C*
r	*2260 kJ/kgk (Table 2)*

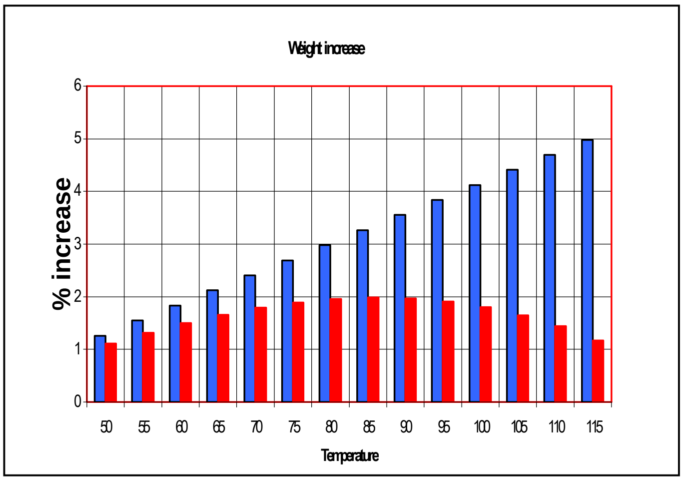
$$W_{max} = \frac{1{,}34 \times (100 - 28)}{2258} \times 100 = \underline{4{,}3\ \%}$$

However, immediately after leaving the conditioning machine the warm yarn bobbins evaporate moisture into the surrounding atmosphere, while they wait for packaging. Naturally, the higher the conditioning temperature, the longer will be the waiting time until the packaging can take place. This evaporation means a loss of moisture and a loss of weight.

Logically, there is a break- even between the energy cost to first warm up the yarns and the losses during the cooling down period. This weight loss prior to packing depends on the temperature (High temperature = high losses, Low temperature = low losses). The following table shows the relation between temperature and weight loss after conditioning:

T	*%*
5 0	*1 2*
5 5	*1 5*
6 0	*1 8*
6 5	*2 2*
7 0	*2 6*
7 5	*3 0*
8 0	*3 4*
8 5	*3 9*
9 0	*4 4*
9 5	*5 0*
1 0 0	*5 6*

Weight loss 20 minutes after conditioning



The conclusion is: With conditioning temperatures of 100 °C the weight increase will be initially up to +4,3 % (!). However, after a cooling period of 20 minutes the

TECHNOLOGICAL BACKGROUND OF CONDITIONING

weight will drop down from +4,3% down by 56% to **+ 1,89%.** The same result of + 1,89% can be achieved at a lower energy level with lower steam temperatures, without the waste of energy. Experience shows that the most economic temperature for yarn conditioning is 65 °C.

Above diagram shows the moisture directly after conditioning (blue) and 20 minutes after conditioning (red). Even though a max weight increase of 5,0 % is possible at 115 °C it drops down to less than 1,2 % prior to packing.

PACKING

Being an important factor to retain the moisture inside the bobbins, the yarn must be packed as soon as possible after the conditioning. Therefore, the cooling period shall be as long as needed (for the cooling down of the bobbins) and as short as possible (to retain the moisture in the package).

With appropriate packing the moisture remains in the yarn for long storing periods. Moisture losses of packed bobbins depend on the quality of packing, as shown in the table below:

Type of package	***Loss per Month***
PE- Plastic Bag	*0,3%*
PE- Plastic Bag in carton board box	*0,1%*
PE- Plastic Bag in PP Bags	*0,15%*
Wrapped wooden Euro- pallets	*0,4%*
Wrapped American plastic pallets	*0,35%*
Open bobbin	*0,5%*

RISK OF BARRÉ EFFECT

In textiles, different degrees of humidity in textiles can have heavy influence in the dyestuff absorption or tension in weaving beams or other similar effects. Therefore, it should be ensured that conditioning is really made from the outer to the inner layers of the yarn bobbins. Uneven humidity can cause shadows on surface, the so called Barré Effect.

MEASURES TO AVOID BARRÉ

To make sure that BARRÉ does not happen, the observation of the saturation point inside the machine is most important.

First, to avoid any trouble, we recommend to strictly keep vacuum over 90% when starting the steaming procedure.

Second, if bobbin diameters are over 250 mm and weights over 2,60 kg, we recommend to use two cycles of vacuum (fractioned vacuum). With the additional vacuum it is proven that bigger bobbins have a much better distribution of moisture.

Third, steam exposure time should be increased but never less than 45 minutes. Hence, often plants are under production pressure and reduce the total time the yarns are exposed to saturated steam. This increases the risk of less absorption at the center of the bobbins and may cause a complaint.

FORCED COOLING WITH TURBOCOOLER

The only way to overcome the limitations of the vacuum conditioning process is the extension of the available temperature difference. As shown before, the upper temperature limits are given by the wax melting point or the rising evaporation level at high conditioning temperatures (losses).

In order to overcome these limitations at the temperature top limits, the temperature difference can be increased by addition of a cooling step prior to conditioning, as follows:

Example:

Material — *Cotton*
c — *1,34 kJ/kgk (Table 1)*
Yarn temperature T_Y — *28°C*

Yarn temperature after cooling: 12°C

Steam Temperature T_S — *65°C*
r — *2340 kJ/kgk (Table 2)*

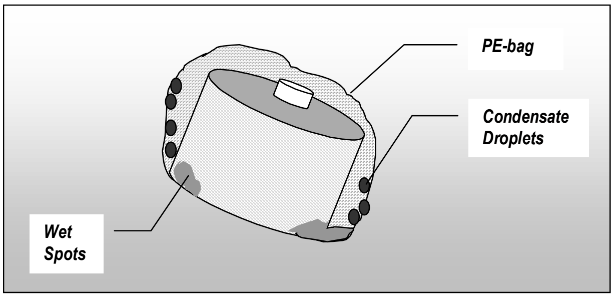
$$W_{max} = \frac{1,34 \times (65 - 12)}{2340} \times 100 = \underline{\mathbf{3,0\ \%}}$$

TECHNOLOGICAL BACKGROUND OF CONDITIONING

FUNGUS - SPOTTING

In the vacuum conditioning process the moisture increase never exceeds the natural absorption capacities of the cotton fibre. Due to the vaporisation of the feed water no additional spores are entrained to the conditioning compartment.

Only in case of high temperatures and too early packing the risk of fungus development rises exceptionally in the wet and warm environment of packed bobbins in PE- bags. Vaporised water from the yarn may condensate on the surface of the bags. Droplets accumulate to form big water droplets. These droplets can get in contact with the cone surface and create wet spots which will the basis for all kind of possible faults and effects in the yarn.



Locally, the moisture can exceed the optimal value around 8,5 % considerably. On wet spots more than 15 % can be monitored being the ideal feeding ground for fungus.

FROM +2% to +3% MOISTURE

Especially when using pin trucks and working in extremely warm climate conditions, PREVAP/ COOLVAP is a true option to increase moisture in the cones.

In course of the continuous development, WELKER technicians have tested various possibilities of controlling the cooling of bobbins inside and outside the conditioning machines. WELKER detains the key patents of **PREVAP and COOLVAP** in this field.

With the utilisation of atomised water vapour molecules inside the conditioning machine with pre- conditioning and cooling treatments, PREVAP and COOLVAP offer better possibilities of **increasing moisture efficiencies up to +3% in only 60 minutes of treatment.**

However, correct adjustment of the PREVAP/ COOLVAP system is key for good quality. Excess of moisture caused by wrong adjustment of the water vapour may contribute to cause fungus spots. Therefore, this technology has to be used with certain restrictions.

If you have any query, please do not hesitate to talk to us.

ELECTRIC RESISTACE MEASUREMENT

A common procedure is the use of electrodes to determine the moisture of yarn. The different electric resistance of fibres at different moisture levels can be converted to a percent figure of the moisture content.

This procedure, however, fails in case of moisture measurement after conditioning because the results are totally influenced by the temperature of the yarn bobbin. At higher temperatures after conditioning, the tested units show extremely high (and wrong) moisture figures. These devices may only be used for rough figures at constant temperatures.

WEIGHT MEASUREMENT

The only and most accurate method to determine the weight is use of a <u>weighing scale</u> before and after conditioning. Single cones are placed on the scale before and 20 minutes after conditioning. Comparison of the scale readings gives the exact figure of weight increase.

Weight increase shall be calculated as follows:

W [%]	*weight increase*
m_b [g]	*weight before conditioning*
m_0 [g]	*weight after conditioning*
m_{20} [g]	*weight 20 minutes after conditioning*

$$W = \frac{m_{20}}{m_b} \times 100 - 100$$

SUMMARY

Conditioning nowadays has returned as key process into the spinning, weaving and knitting industry. Although the machines basically appear to be simple, the technology involved demands

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TECHNOLOGICAL BACKGROUND OF CONDITIONING

understanding and attention as its implications can improve drastically quality but also create a complaint.

Summarising we can say:

- Yarn conditioning is based on condensation of steam inside yarn packages. The condensate is absorbed by the yarn.

- Weight Increase is only determined by vacuum level and temperature difference and not by "direct" or "indirect" steam.

- The max. weight increase is determined by the quantity of steam which is condensing inside the cones. This quantity depends only on the steam temperature and the yarn temperature.

- Waxed yarns can only be treated up to the wax melting point. Thus the weight increase is limited.

- The economically suitable conditioning limit is the temperature of appr. 65°C. Higher temperatures result in more weight along with higher weight losses prior to packing.

- Only high vacuum (around 95 % - 50 mbar) creates the conditions for uniform moisture penetration and optimal heat transfer. For higher diameters and weights a second vacuum cycle is recommendable.

- With cooling the available temperature range can be increased to achieve higher moisture regain (TURBOCOOLER).

- Also the steaming time has influence on the weight increase. Bigger cone diameters require longer times for utmost weight increase.

- Conditioned yarn must be packed properly in order to conserve moisture regain for long periods. Yarn can only be packed after a cooling time of appr. 20 minutes.

- Weight measurement is the only reliable method to determine the actual weight increase. Electric resistance electrodes create false results due to their influence by temperature.

- Vacuum conditioning creates no additional risk of fungus as long as the natural moisture absorption is not exceeded. A level of 8,5 % should not be exceeded.

- Weight measurement is the only reliable method to determine the actual weight increase. Electric resistance electrodes create false results due to their influence by temperature.

- BARRÉ effects can be avoided by correct utilisation of the conditioning technology.

- PREVAP/ COOLVAP is appropriate for warm climates but under certain process restrictions; it is rather applicable using pin trucks instead of pallets thus avoiding excessive accumulation of water on the surface.

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