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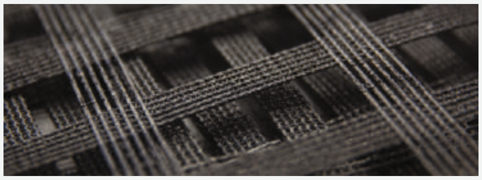

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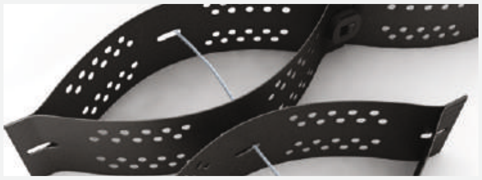

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EDITOR'S DESK

Dear Readers,

Greetings!!

Research with persistent and focused efforts lead to a positive result. Fostering research and providing a platform to publish quality research papers and related articles has been a continuous effort of BTRA Scan. We are working hard to help the journal in climbing up the ranking ladder. In continuation to this effort, I am delighted to present to our readers the 2nd issue of 52 Edition of BTRA SCAN.

This issue has papers from the different domains such as Development of high-performance fiber, Surface modification by plasma to improve the adhesion property, Water conservation in wet processing. Now we are open for authors from outside so researchers can send their original articles, case studies, research reviews or empirical contributions for publication in our journal.

I thank my entire publishing team for all their support. Together we would work towards making the journal a truly influential publication. Comments and suggestions are always welcome.

Our sincere thanks to all the reader and contributors for their support and interest.

T V Sreekumar, PhD
Director, BTRA

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From Industry 4.0 to Research 4.0. Development of high-performance fibres in the light of digitisation

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Abstract

The research work in the field of high-performance fibres is characterised by a high degree of adaptation needs. Research facilities must be able to be adapted after initial experiments and the knowledge gained thereby. The necessary adjustments are made under the conditions of a highly complex manufacturing process, which is determined by many influencing parameters. The development of high-performance fibres demands an efficient system and, in part, self-optimising experimental working system, which must be intelligent in gathering data from the process and flexible in enabling the rearrangement of the process. Research 4.0 is a systematic approach aiming to support researchers working on the development of innovative yarns. Each module within the line represents a production step and is equipped with a PLC to control itself and to organise in association with other modules in the plant. The control hierarchy has an intelligent modular structure that configures itself according to the arrangement of every single module given by the hardware and the interfaces within the system. This paper will present the implementation of Research 4.0 as a tool for the development of a product from the idea to the practical implementation. Such a task needs a modular conceptual approach offering the required flexibility for the complete validation process: principle > process > product.

Keywords

Industry 4.0, Research 4.0, High-Performance Fibres, Development, Modular Design, Pilot Plant, Lab-scale Plant

Citation

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1.0 History of Digitisation

In the old, analogue world, there were things above all. Things were linked to names and pictures. Thus, the world of words and the world of images developed into the first stages of abstraction. The next level of abstraction was the mapping of things, words and pictures into numbers. That was the birth spark of the world of data.

The most common way to define the world of numbers is by using ten digits (0 to 9). However, it was the invention of the binary number system by Gottfried Wilhelm Leibniz (1697) which allowed the representation of all numbers with only two digits (0 and 1). Thus, the world became mathematical and the fundament for digitisation was laid as it is the process of putting information into the form of a series of numbers 0 and 1 so that it can be understood and used by a computer or processed electronically. In 1788, Joseph-Louis de Lagrange represented in this work "Méchaniqueanalitique" the thesis, that the world can only be completely described using algebraic operations, hence turning the mathematical description of the universe into a digital realm.

George Boole proves in his work "An Investigation of the Laws of Thought" (1854), that logic and algebra are identical. Gottlob Frege followed with his "conceptual notation" of non-symbolic terms in "The Foundations of Arithmetic" (1884). This analysis of logical concepts and the machinery of formalisation was essential to Bertrand Russell's and Alfred North Whitehead's"Principia Mathematica"(3 vols., 1910–13), to Bertrand Russell's theory of descriptions, to Kurt Gödel's (1906–78) incompleteness theorems, and Alfred Tarski's (1901–83) theory of truth. These theories paved the way for mapping thinking to logic and logic to math. Thus, the base of programming languages was created and algorithmic languages like ALGOL 60 were the first breakthrough in digitisation.

In parallel to the mathematisation of the world, a multitude of

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inventions were still necessary to link things, words and images as well as sounds too logical data. The development of telecommunications from Heinrich Hertz (1886-1888) to the transistors of John Bardeen, Walter Brattain and William Shockley (1946) gave birth to wireless radio technology, which has enabled the transmission of data through the space separating emitter from the receptor. On this basis, the technical infrastructure of a digitalised world emerged. The developments such as telegraph, telephone, television, radar, broadcasting, satellite and finally the Internet have been shaping the technical network that today enables global data exchange.

In the twentieth century, based on technical innovations combined with computer technology, a closely linked communication and information network of mobile media emerged, which forms the basis for today's visions of the future. With the convergence of the various communication technologies on which the various digital control systems are based, the basis for the Internet of Things has been laid and thus for Industry 4.0 and Research 4.0.

2.0 Industry 4.0

In 2012, the German Federal Government set up a group of experts to analyse the opportunities and perspectives of information and communication technologies. As a future project of the high-tech strategy of the Federal Government, Industry 4.0 was born as a working concept. A group of experts was assigned the task of investigating the possibilities of information technology and digitisation in production research. The topic should be analysed across industries and disciplines for Germany as a business location. The inclusion of disciplines outside of the industry creates accents and emphases far beyond the core topic.

The core element of the "Industry 4.0" concept is the intelligent factory - the smart factory. The expert group appointed by the German Federal Government defines the concept of the intelligent factory as follows: "It is characterised by a new intensity of socio-technical interaction of all actors and resources involved in the production. The focus is on the networking of autonomous, self-controlling, self-configuring, knowledge-based, sensor-supported and spatially distributed production resources (production machines, robots, conveyor and storage systems, operating resources), including their planning and control systems. The smart factory is characterised by end-to-end engineering that includes both production and the product that seamlessly meshes the digital and physical worlds. The smart factory is also embedded in cross-company value networks. "

From the perspective of information technology, the eye-catching name "Industry 4.0" is used to: “propagate the widespread entry of information and communication technology and its networking into an Internet of Things, Services and Data that enable real-time production capability. Autonomous objects, mobile communication and real-time sensors allow new paradigms of decentralised control and ad-hoc design of processes. The ability to respond quickly and flexibly to customer requirements and to economically produce large numbers of variants at low batch sizes will increase and thus increase competitiveness once again. New forms of customer-integrated business processes become possible. The full-bodied promised "fourth industrial revolution" seems within reach.”

Therefore, the technology should be intelligent and able of organising itself. The production line is divided into modules, which become cyber-physical systems that network with each other. Ahrens tries to get to the bottom of this terminology and delimited the artificial intelligence of technology from the human-centred concept of intelligence. He puts it: “Against such a background, it does not matter if technology is artificially intelligent or not, but on the fact that it supports people in bringing their intelligence and autonomy to full effect.”

3. Transferring the principles of Industry 4.0 to Research 4.0

Adapting a definition of the main four goals in Industry 4.0 made by the German Federal Ministry of Education and Research , a future project Research 4.0 shall aim to enable the development of innovative products (e.g. high performance fibres) by achieving the following goals:

- Delivering a high degree of flexibility in the spinning plants under the conditions of high adaptability of the processes to new findings from the research work.
- Equipment suppliers and researchers work in close cooperation during the decision-making and development process.
- The development of new products is accompanied by high-quality services.
- Intelligent monitoring and decision-making processes are designed to enable researchers to control their experiments in real-time and to easily make optimisation adjustments.

VDMA (the German Association of the Mechanical Engineering Industry) has developed a toolbox to support idea generation in the context of Industry 4.0. The stages of development represent the path to the realisation of the visionary final stage of Industry 4.0. We have tried to measure and evaluate our development according to this realisation concept.

The toolbox allows the comparison of products with a benchmark of different goals that need to be met for a successful implementation of the vision of Industry 4.0 :

- ◆ Product related aspects
  - Integration of sensors/actuators
  - Communication and connectivity
  - Functionalities for data storage and information exchange
  - Monitoring
  - Product-related IT services
  - Business models around the product

- Production related aspects
  - Data processing in production
  - Machine-to-machine communication M2M
  - Company-wide networking of production
  - ICT infrastructure in production
  - Man-machine interfaces
  - The efficiency with small batches

4. Implementation of Research 4.0 – MultiMode®

Research 4.0 at DIENES aims to enable researchers to work on their development optimally supported by the system. The approach chosen has been a human-centred approach to create a system that can operate autonomously and with the capacity to organising itself. Either the starting point is a technology that shall be equipped with social skills and characteristics such as intelligence, autonomy and self-organisation, or the human being is the starting point and the technology is the one to be reshaped to better support people in bringing their capabilities and qualities to full effect .

The research work in the field of fibre development is characterised by a high degree of adaptation needs. The research facilities must be able to be adapted after initial experiments and the knowledge gained thereby. The necessary adjustments are made under the conditions of a highly complex manufacturing process, which is determined by many influencing parameters. This results in the following requirements for the flexibility of the electronics control of the research facilities:

- INTEGRATION: Easy integration of new production modules
- SCALABILITY: Easy replacement of production modules with modified specifications (e.g. throughput).
- FLEXIBILITY: Easy change of the order of production steps through configuration and integration of measurement and analysis sensors through multi-loop control
- HIGH PERFORMANCE: Intelligent production modules for fast process interventions and synchronisation of the process control by a master control
- ANALYTICS: Convenient monitoring and evaluation options of the process parameters by a higher-level configurable PC-based process monitoring system.

The development of new innovative filaments demands an efficient systematic and, in part, self-optimising experimental working system, which must be intelligent in gathering data from the process and flexible in enabling the rearrangement of the process. DIENES' implementation of the Research 4.0 approach is called Multimode®. Due to its flexibility, Multimode® offers a tool for the development of a product from the idea to the practical implementation. Due to its modular conceptual approach, a MultiMode® pilot plant is suitable for the complete validation process:
principle ➔ process ➔ product.

	1st Phase Validation of Principle	2nd Phase Validation of Process	3rd Phase Validation of Product
Filaments:	1 – 50	20 - 400	100 – 4.000
Threadlines:	1	1	1-4
Melt spinning:	100 – 500 m/min	300 – 1.500 m/min	1.000 – 5.000 m/min
Wet spinning:	5 – 25 m/min	10 – 100 m/min	20 – 200 m/min
Throughput:	10 – 250 g/batch	100 – 1.000 g/h	1.000 – 10.000 g/h
	x10 →	x10 →	
Machine size:	300 x 100 mm	3.000 x 500 mm	30.000 x 1.500 mm

Figure 1 - MultiMode® – Validation process of principle, process and product (Source: DIENES)

5. The structure of the MultiMode® system

Under Multimode® every module represents a production step and can store knowledge at the module level and act according to the function of the module in interaction with other modules. The Multimode® system runs on three levels:

- Slave (level 1 - MMS: MultiMode® Slave)
- Master (level 2 - MMM: MultiMode® Master)
- Upper control (level 3 - MME: MultiMode® Explorer)

The requirements for a flexible control system have reached a very high technical level alongside expectations from the user regarding ergonomic demands for the interaction with HMI (Human Machine Interface) and the equipment. The MultiMode® concept fulfils the following requirements:

- Easy extension or reorganisation of the modules in the system.
- Various process ideas can be tried out in one day by modifying the modules.
- Enables the operation of individual modules outside the plant.

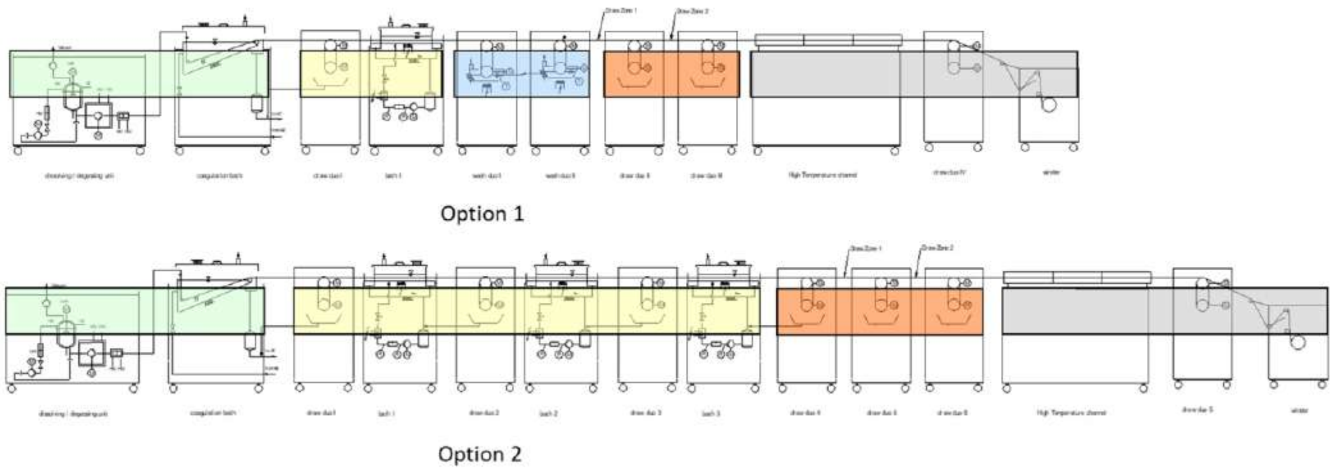

Figure 2 - MultiMode® – Configuration change without programming (Source: DIENES

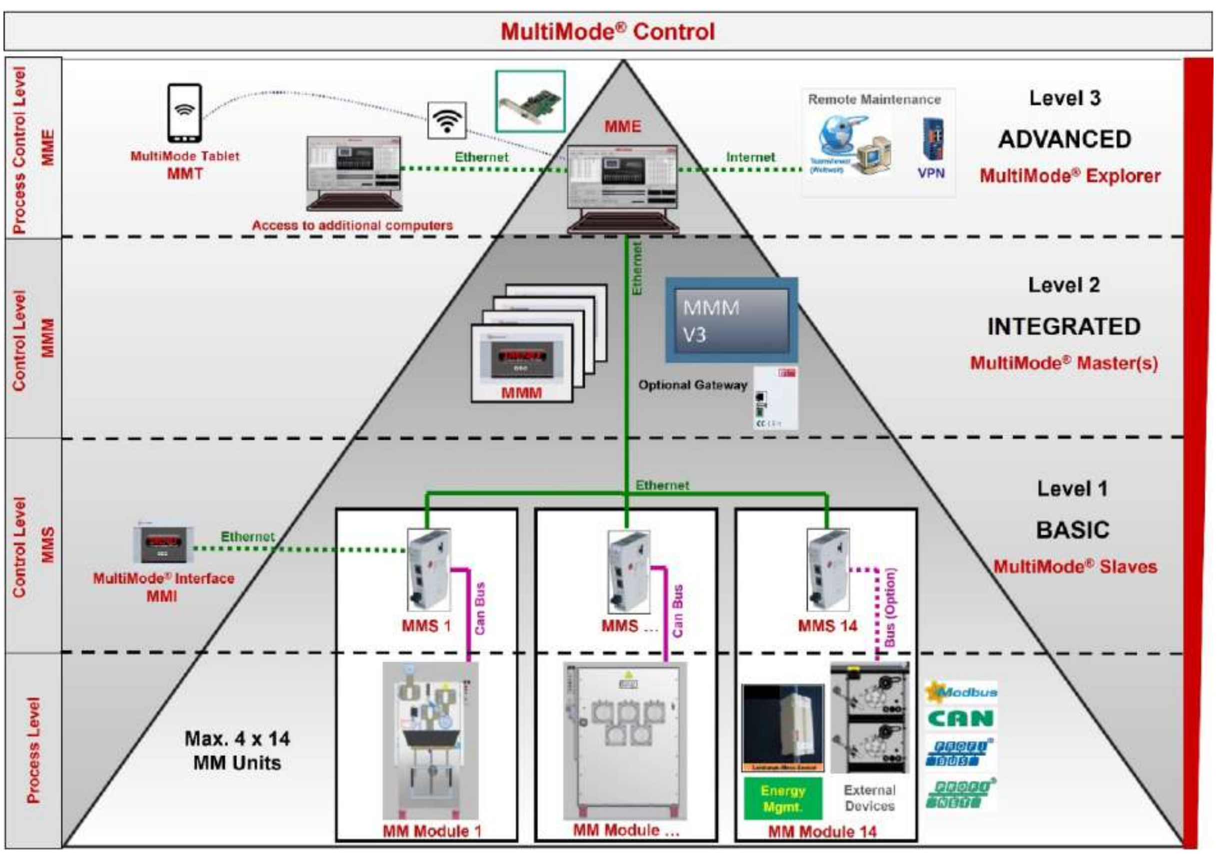

Figure 3 - MultiMode® – Hierarchical structure (Source: DIENES)

The configuration of the system follows a hierarchical structure. The foundation is formed by the yarn treatment modules such as the washing duo, washing bath or spinning unit. Each of these MMS modules is equipped with a MultiMode® box, hence it is equipped with its intelligence based on a PLC to control itself and to organise the module in association with other modules in the plant. A single module can automatically take over a thread from a non-MultiMode® plant and process it, e.g. as an additional drafting stage or to eject a thread from a system and wind it up.

Control hierarchy has an intelligent modular structure that configures itself according to the arrangement of modules given by the hardware and the interfaces within the system. Thus, a structure is realised that allows new arrangements by configuration and without any programming work required. From a control perspective, the process level with the MultiMode® boxes forms the control level "BASIC" with the MMS modules. Up to 14 of these basic modules can be switched to one MMM. This second control level "INTEGRATED" is organised by the MMM, which is also responsible for configuring and forwarding the information to the computer-based MME. The computer level control (MME) can be connected with 4 MMMs, which gives the possibility of 56 MMS modules connected to their corresponding MMM with their local input displays or to an industrial PC via gateways allowing all visualisation and control options using a touch screen. The upper control level is the process control level "ADVANCED" and organises the elegant functions of the system.

The functions included at the MME include features like:

- Real-time evaluation of all sensors, which can be combined with each other in the graph
- Data logging with a connection to an SQL database every second.
- Data management. The system has the possibility to transfer recorded data to EXCEL for further analyse.
- Access control with user administration (password protected) with different access levels to the operation system
- Tracking of all operator inputs (operator login required)
- Recipe management for saving current settings as a recipe under a freely assignable name to be used at a later moment if necessary
- Alarm logging
- Mini-monitoring. Single parameters can be monitored in a small screen-in-screen application in real-time. It is possible to add additional parameters to the "mini-monitor" and generate ad-hoc visualisations making it a quick and easy way for the user to analyse correlations between different production parameters.
- Long-term monitoring of operation parameters.
- The printer function with no limitations and allows printouts and screenshots of any view or diagram on the screen.
- Notepad function for making notes on the screen. When printing the full screen, these notepads are also printed.

If the MultiMode® line is connected to a wireless network of the Internet (e.g. via VPN), the MME offers additional functions: remote access to the plant for service and operation, operating the line via mobile phone or tablet (via DIENES app), etc.

6. Evaluation of the MultiMode® system with the Industry 4.0 benchmark

In section 3 a benchmark developed by VDMA was presented as a possible way to validate the adequacy of a concept or product to the principles of Industry 4.0 . In this section, VDMA's guideline will be used to evaluate the MultiMode® approach as a Research 4.0 solution.

6.1. Product related aspects

6.1.1. Integration of sensors/actuators.

Integration of sensors and actuators has been a standard in research facilities for a long time. As an example of further integration of sensors/actuators, the speed control of godets is nowadays solved by thread tension control instead of fixed draw ratios. Thus, yarn tension sensors are used, which are analysed and interpreted to readjust the godets' drives accordingly.

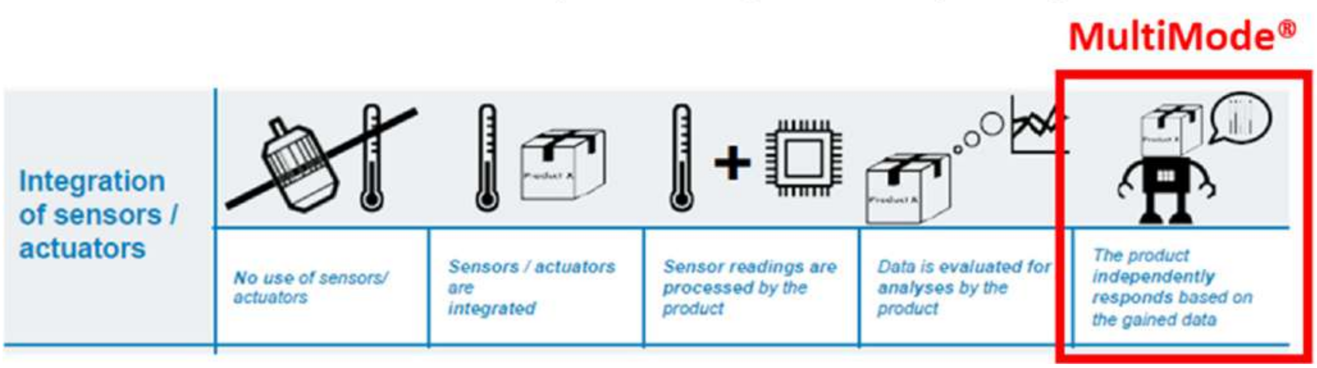

Figure 4 - Integration of sensors/actuators (Source: VDMA)

6.1.2. Communication and connectivity

MultiMode® systems have open interfaces and are able to integrate various third-party products. It is compatible with today's common BUS systems. Access to the Internet allows a remote connection with the system. Remote service and support can be delivered this way.

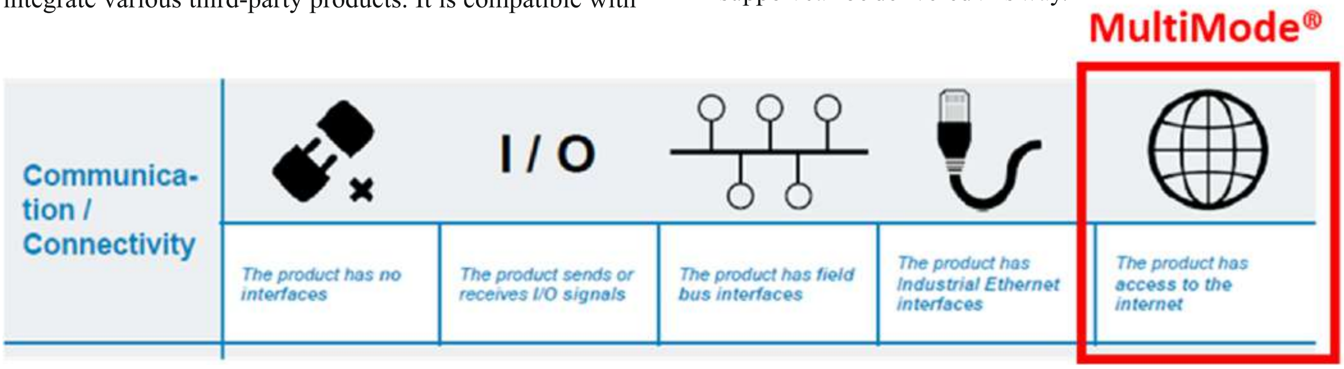

Figure 5 - Communication and connectivity (Source: VDMA)

6.1.3. Functionalities for data storage and information exchange.

The Multimode® System has an upper control system (MME) in which elegance functions are performed. This ranges from a single data monitoring that allows the researcher to explore system contexts and to analyse time series of data taken every second. To confirm correlations of a pair of data, the researcher can initiate long-term monitoring for confirmation and record the data every second within a defined time. Data can be graphically displayed. The selection of data to be recorded is arbitrary and freely selectable as every data is accessible. The system can transfer the data in a processable format (e.g. EXCEL file) for further analysis.

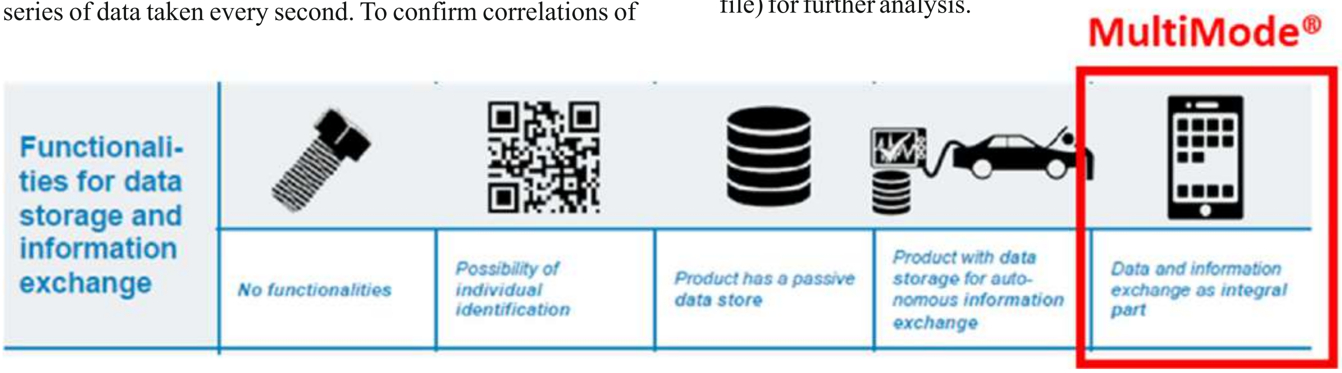

Figure 6 - Functionalities for data storage and information exchange (Source: VDMA)

6.1.4. ICT infrastructure in production

The infrastructure of Information and Communications Technology (ICT infrastructure) has different priorities in research than in production. The network does not have to go beyond the normal connection to the intranet and the normal connection within the company. Connecting a MultiMode® system to research partners is possible. Partners can access the system remotely via software (TeamViewer) and also call technical support via remote access service. Experimental design and statistical trial optimisation are still outside the MultiMode® system. Integrating these tasks and developing concepts for automation here are further development stages for the future.

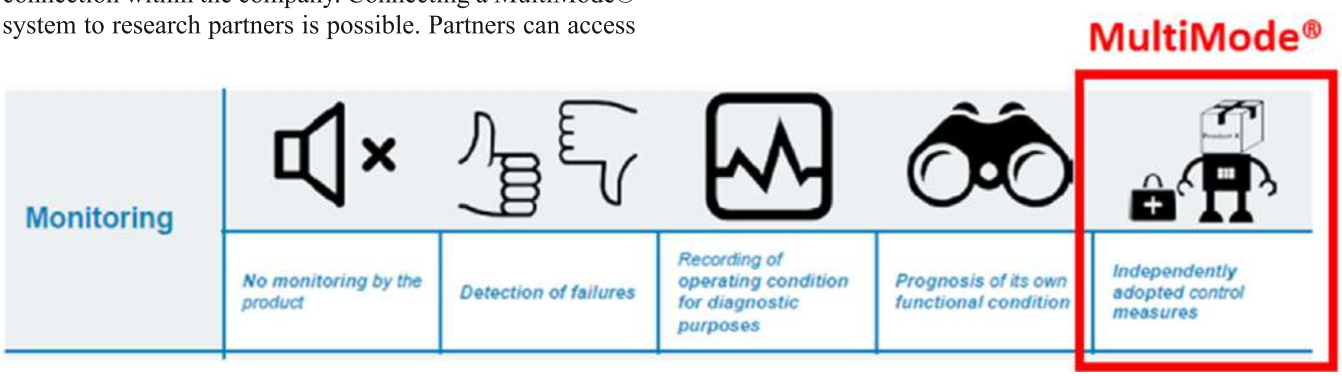

Figure 7 - Monitoring (Source: VDMA)

6.1.5. Product-related IT services

If access via VPN is granted, a full range of remote support and service is possible. Access to the line via mobile devices can be also organised this way.

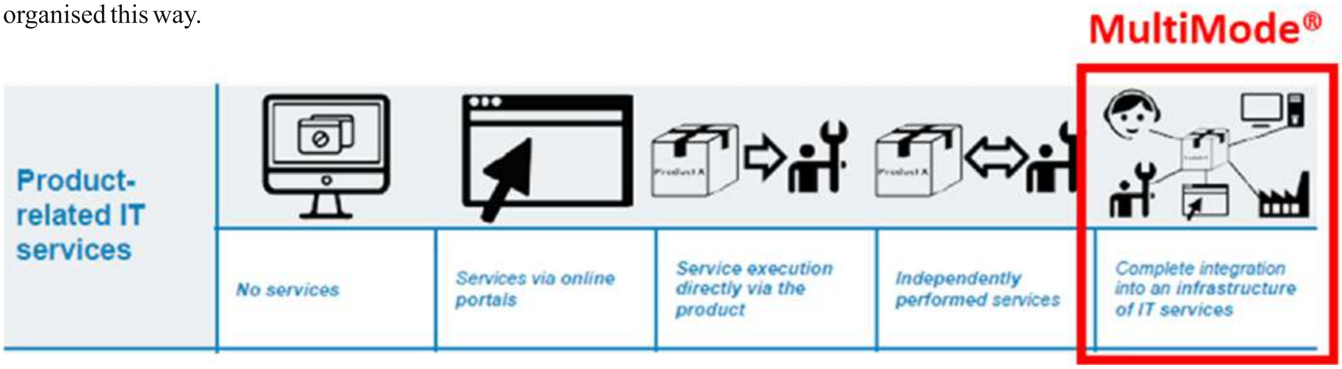

Figure 8 - Product-related IT services (Source: VDMA)

6.1.6. Business models around the product

The remote connection and the possibility to store and monitor big amounts of production data make a complete integration of services possible.

Figure 9 - Business models around the product (Source: VDMA)

6.2. Production related aspects

6.2.1. Data processing in production

Data are collected and the process is monitored automatically while the evaluation of the running conditions of the plant is still done manually. The evaluation of the dependency on various parameters is supported by analysis tools and allows systematic correlations to be identified in prototype plants in order to automate processes in subsequent production on large-scale plants.

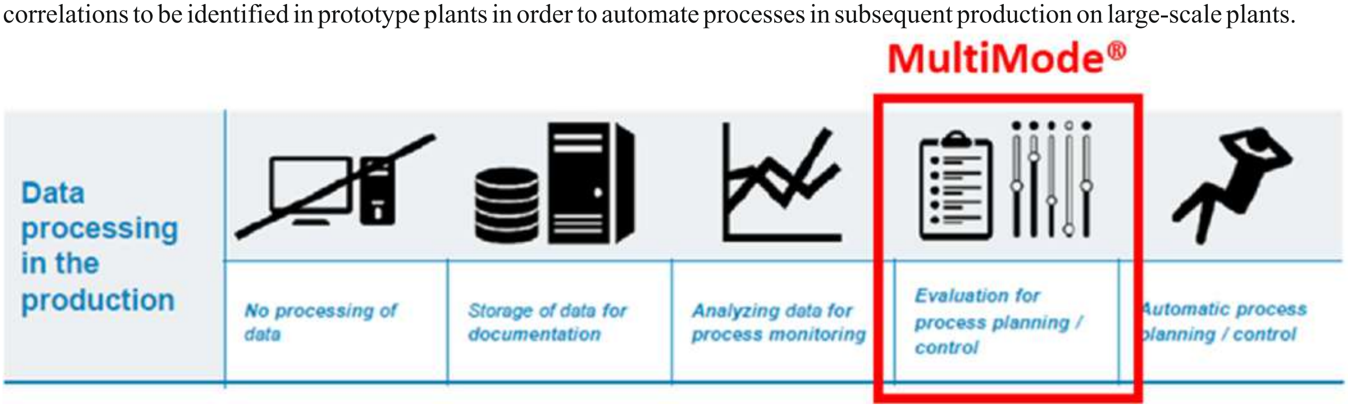

Figure 10 - Data processing in production (Source: VDMA)

6.2.2. Machine-to-machine communication M2M

MultiMode® provides the necessary interfaces for intelligent communication between the modules. A special feature is the self-organisation of the MMM after a rearrangement of the MMS modules at the machine level. Communication with external units, i.e. access to the system from the outside via mobile devices or the Internet or even reporting an alarm of the system to external devices is possible.

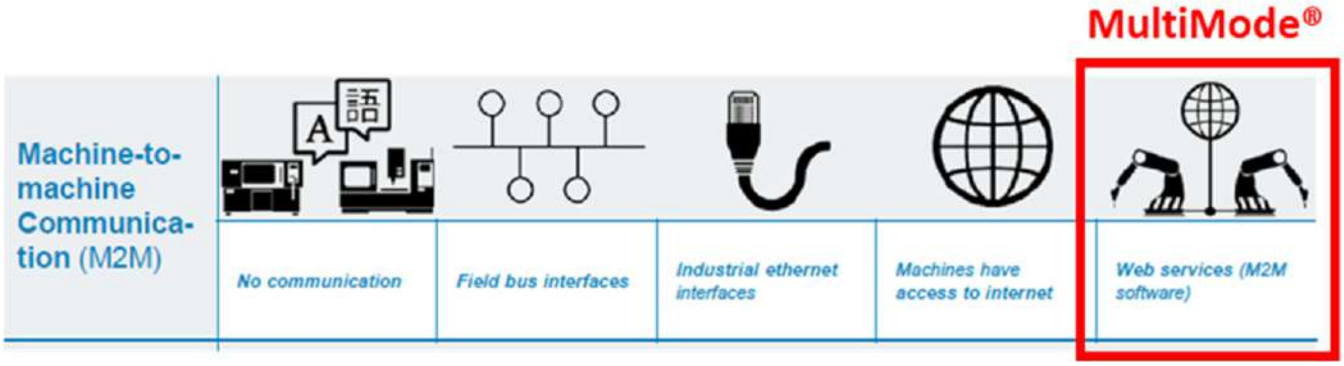

Figure 11 - Machine-to-machine communication M2M (Source: VDMA)

6.2.3. Company-wide networking of production

Company-wide networking of production

An enterprise-wide communication of the individual research results, which are obtained by pilot lines in the research departments, does not seem as a main goal. Within the research plant environment, it is possible to allocate the respective running conditions to the second of the produced yarn quantity and to communicate them within the researchers' network. This information is available in a processed format. If the research team wants it, the results from their work can be stored in a data server (SQL)which can be used as a knowledge database.

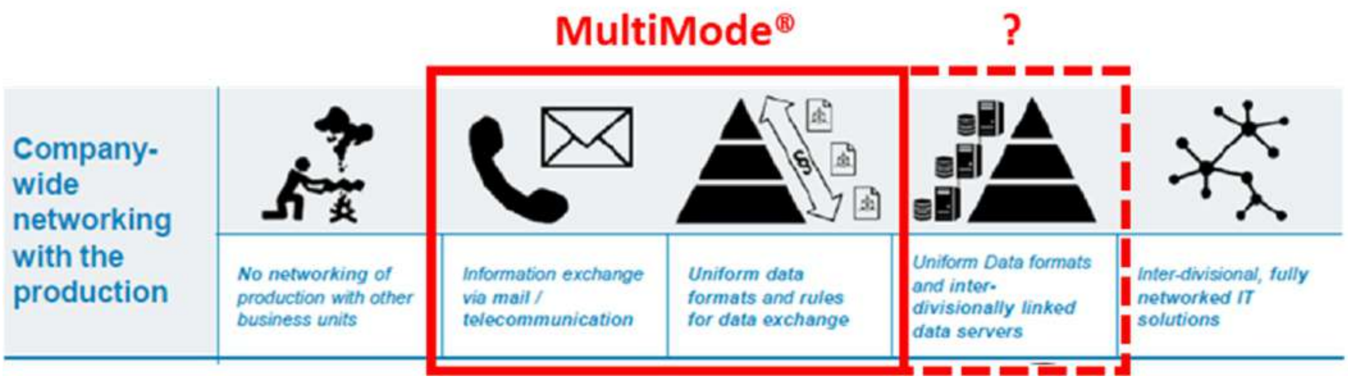

Figure 12 - Company-wide networking of production (Source: VDMA)

6.2.4. ICT infrastructure in production

The infrastructure of Information and Communications Technology (ICT infrastructure) has different priorities in research than in production. The network does not have to go beyond the normal connection to the intranet and the normal connection within the company. Connecting a MultiMode® system to research partners is possible. Partners can access the system remotely via software (TeamViewer) and also call technical support via remote access service. Experimental design and statistical trial optimisation are still outside the MultiMode® system. Integrating these tasks and developing concepts for automation here are further development stages for the future.

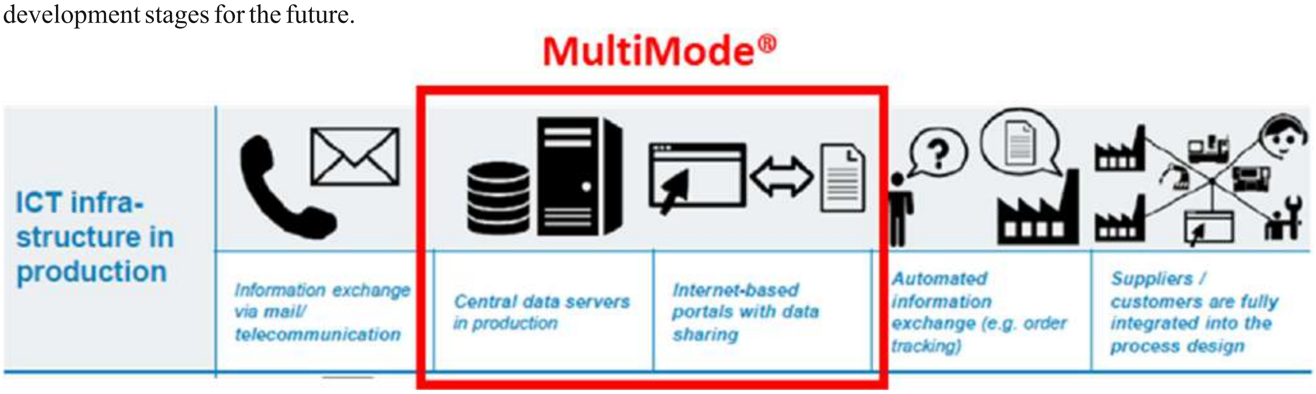

Figure 13 - ICT infrastructure in production (Source: VDMA)

6.2.5. Man-machine interfaces

The use of mobile devices allows watching and controlling functions. Apps have been currently developed that use a mobile device to exchange data with the MultiMode®control system via a WLAN limited to the system. The setting of on-site parameters exactly at the point where the yarn forms or the yarn runs over a pair of godets allows the researcher to observe the change in the process in real time. Operators don't have to walk all the way down to MMM or MME.wants it, the results from their work can be stored in a data server (SQL)which can be used as a knowledge database.

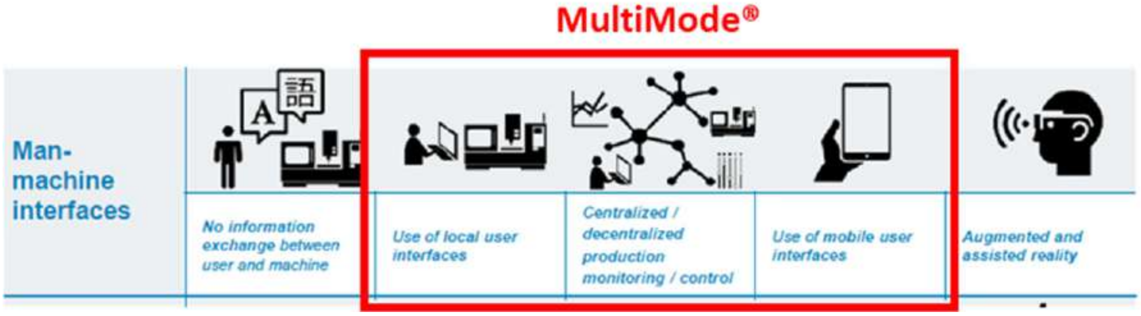

Figure 14 - Man-machine interfaces (Source: VDMA)

6.2.5. Data processing in production

In terms of a high degree of flexibility, which makes it possible to carry out experiments efficiently and goal-oriented, two tools have to be mentioned: very detailed recipe management allows the storage and use of operational parameters from already performed experiments and the continuous tracking and monitoring of operational parameters.

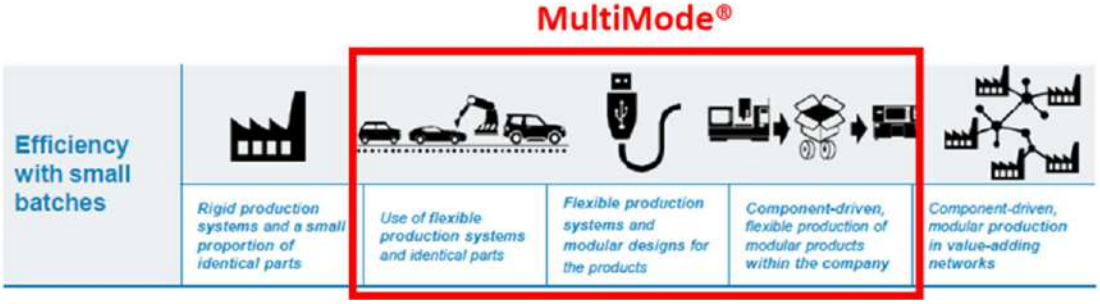

Figure 15 - Data processing in production (Source: VDMA)

7. Conclusion

Many aspects of the Industry 4.0 approach, which have been developed for industrial production, are transferable to research production facilities resulting in a Research 4.0 approach. Full integration into the logistics chain of production is less important in this case. However, the researcher needs to be enabled to manage digitally the entire process flow of his research work. Research 4.0 offers transparency within the working process and traceability of the results supporting the research team ins its creative work and keeping open all paths to innovative developments.

MultiMode® has been presented as a Research 4.0 solution developed by DIENES. The approach chosen has been a human-centred approach to create a system that can operate autonomously and with the capacity to organising itself. A benchmark developed by German experts has been used to evaluate how MultiMode®meets most of the requirements drawn for Industry 4.0. All product-related aspects are met to their full extent while some production-related need some improvement: e.g. integration of big data analysis to recognise patterns and apply them to automatic process planning and control, implementation of augmented reality solutions to enhance the man-to-machine interaction (e.g. VR googles), etc.

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Theories of adhesion and plasma surface modification of textiles for adhesion improvement : A review

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Abstract
This paper gives the review of adhesion mechanisms and use of plasma technology in textile for improving the adhesion of coated textiles. The definition of adhesion is given as the "tendency of dissimilar particles or surfaces to cling together by physical, mechanical or chemical forces". Adhesion occurs as a result of intermolecular forces acting between the adhesive and adherend. The different mechanisms of adhesion including chemical bonding, mechanical interlocking, Adsorption and wetting, Diffusion and Weak boundary layers (WBL) have been reviewed. Methods of adhesive application on textiles and testing of the adhesive joints are also discussed.

Key words:
Adhesion theory, Coating, Peel off, Plasma, Testing

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1.0 Introduction:

Bonding by the adhesive is one of the oldest techniques in textiles. The main purpose of adhesion by adhesive bonding is a partial or complete replacement of conventional mechanical bonding techniques such as riveting, soldering, bolting etc. it has certain advantages over mechanical bonding namely better stress distribution, reduced weight, and better aesthetic. However, adhesion is not only related to adhesive joints but it is concerned everywhere when solids are brought in contact to keep them together. The definition of adhesion is given as the "tendency of dissimilar particles or surfaces to cling together by physical, mechanical or chemical forces". Adhesion occurs as a result of intermolecular forces acting between the adhesive and adherend. Adhesion and interfacial strength have a direct influence on the properties of the final product (coated fabric). The degree of adhesion is dependent on cohesive forces acting within the adhesive and interactions between adhesive and adherend. Therefore, work of adhesion Wa, that is the force required to break the bond is given as

$$W_a = \gamma_1 + \gamma_2 - \gamma_{12}$$

where γ_1 and γ_2 are the surface tension of components 1 and 2, γ_{12} is interfacial tension between 1 and 2.[1].

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The above equation suggests that adhesion is a function of the interfacial energy of material present in intermolecular interactions between the substances. Usually, the work of adhesion is directly proportional to adhesion strength. Molecular affinity is the primary requirement to achieve better adhesion. Therefore, chemical compatibility (at the molecular level) with substrata is necessary for coating. It is difficult to get good adhesion when two substances are chemically incompatible with each other. In such cases, adhesion can be improved by surface modification through physical, chemical, grafting and plasma treatment[2] .

Adhesion is often misunderstood with cohesion, there is a distinct difference between the two. Cohesion is related to the intermolecular forces acting within a substance. It is important to understand the difference between adhesion and cohesion to distinguish types of failure when bond breakage occurs[3].

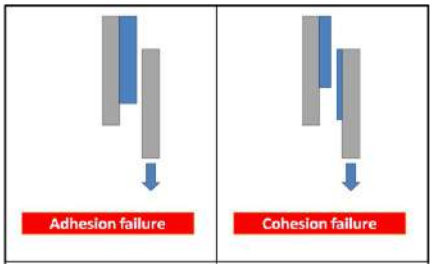

Figure 1: Types of bond failure in adhesion bonding

A bond can fail in multiple ways. Figure 1 shows the type of bond failure. Adhesive failure is at the interface between adhesive and adherend. This type of failure implies that adhesive and adherend both have greater strength than the bond between the two. Cohesive failure is within the adhesive and adhesive materials remain on both substrates. Intermolecular forces acting within the adhesive are weaker than that of the bond strength. When the substrate fails before breaking the bond and the adhesive remains intact, the failure is known as a cohesive failure of the adherend.

2.0 Mechanisms of adhesions:

There is no universal theory or mechanism of adhesion under which the reason for good bounding between adhesive and adherend can be explained. However, it is difficult to apply any single mechanism to explain adhesion because it involves several scientific fields including material science, physical chemistry and material interface, macromolecular science, rheology and mechanics and micromechanics of fracture. Following theories have been proposed based on the interactions between adhesive and adherend [4-6].

2.1 Mechanical interlocking:

It can be explained as the penetration of adhesive into the micro-cavities of the substrate. Initially, mechanical interlocking was thought as the only mechanism for adhesion to occur. To function in mechanical interlocking theory, the adhesive should flow and fill into porous, micro-void, cavities of the substrate and displace the trapped air at the interface and get solidified and lock on the substrate[4,5,7].

It is believed that increased surface roughness improves mechanical anchoring by increasing the total contact area, formation of clean surface, and highly reactive surface formation. This theory suggests that roughening of the surface is favourable for increased adhesion strength by giving peak and valley effects and increasing the contact area with adhesive. However, the substrate should be wet by adhesive otherwise increased surface area can only increase the trapped air at the interface negatively affecting the adhesion strength[5,7].

2.2 Adsorption and wetting:

Adsorption or wetting theory suggests that adhesion is the result of molecular contact between an adhesive and the adherend and the forces developed between them. The bond formed because of the adsorption of an adhesive over the surface of the adherend is generally assigned as van der Waals forces. To develop those forces the adhesive must make intimate contact with the adherend surface.

A method of creating a continuous link between an adhesive and the adherend is called "wetting". An adhesive should flow into the pores of the substrate to achieve good wetting. Poor wetting results when adhesive forms a bridge over the surface perturbations. This results in the less actual contact area between the adhesive and adherend which is the main reason for less bonding strength. Complete, spontaneous wetting to occur, either substrate should have lower surface energy or the adhesive should have lower surface tension. The surface energy of the substrate can be modified by surface modification using various techniques, one of which is plasma technology[8,9]. It is discussed in great detail in the upcoming part.

2.3 Electrostatic interactions:

This theory of adhesion is less considered a cause for adhesion strength as the contribution of electrostatic forces is negligible when compared to van der Waals forces. This theory was proposed by Deryaguin and co-workers[10] in 1948. They suggested that an electrostatic interaction (transfer of electrons) between the adhesive and substrate can occur when they use different electronic band structures to equalize the Fermi levels. Therefore, the formation of an electric double layer at the interface takes place. When peel-off tests are performed electrical discharges can be observed which supports the theory of electrostatic interactions. However, the electrical phenomena observed are the result of bond failure and not the reason for high bond strength[5,11].

2.4 Diffusion:

It works on a simple principle that if two polymers are kept in close contact above their glass transition temperature, the long chain molecules will inter-diffuse and form a strong bond by creating an interface. It is also called "autohesion" as it refers to the self-adhesion of polymers. To apply diffusion theory the polymer should fulfil two main conditions: that is both the adhesive and adherend should be chemically compatible in terms of miscibility and molecular chains of both should have mobility. Therefore, diffusion theory is less applied as in rear cases the adhesive and adherend are miscible in each other. Good examples where diffusion theory is applied are solvent or heat welding of thermoplastic materials[11,12].

2.5 Chemical bonding:

It is simply accepted that chemical bonds that form an interface of adhesive and adherend participate in the adhesion strength of both materials. Bonds that are covalent and ionic are stronger than the hydrogen and van der Waals bonds. A covalent bond has a strength in the range of 100 to 1000 kJ/mol; however, the strength of van der Waals does not exceed 50 kJ/mol. The formation of a type of chemical bond depends on the reactivity of both adhesive and adherend. For materials having polar groups such as carboxylic acid the chances of occurring covalent bonding is high as compared to that of hydrophobic materials. Covalent bonds are likely to occur in cross-linked adhesives and thermoset coating. It is the most important condition that mutually reactive groups should be present in adhesive and adherend to form covalent bonds. It is the most durable and strongest bond. Those conditions can be fulfilled by surface modification of adherend by techniques such as corona, flame and plasma[11,13,14].

2.6 Weak boundary layers (WBL):

Weak boundary layers can arise from the adherend, adhesive, environment or by the combination of any of these three. Bond failure occurs cohesively at the weakest component of the joint. When impurities concentrate near the bonding surface and form a weak attachment with the surface then WBL occurs. In adhesion, the most important task is to remove WBL before the application of adhesive. The most common elements that form WBL are trapped air at the interface, oil on the surface of the adherend, antistatic agents etc. To avoid the formation of WBL generally, the surface of the adherend is subjected to surface cleaning, this can be achieved by plasma treatment. Plasma treatment of the material results in a cleaning effect which in terms removes the surface impurities[7,8,13].

3.0 Methods of adhesive application for coated textiles:

The main purpose of the coating is to provide specific properties to the final product which can increase its usability and application in various areas. The coating is the process in which a layer of polymeric material is directly applied over the surface of the substrate. The primary requirement is that the coating layer should adhere to the substrate. The adhesion of the polymeric material (adhesive) can be influenced by various coating methods also; besides the surface structure of the substrate. Calendaring, Flexible film laminating, Knife coating, Roller coating, Nip coating, Cast coating, Extrusion coating, Spray coating, Foam coating, UV-Cured coating and Powder Coating are the techniques used for coating depending on the type of adhesives or polymeric material[15]. Out of those methods, knife coating is commonly used in textiles.

3.1 Knife coating:

A coating chemical is applied near the knife edge and the knife spreads the coating chemical over the surface of the substrate. The thickness and the weight of the final coating are controlled by a metering knife by adjusting the pressure and distance. It is commonly used for highly viscous coating chemicals. Three types of knife coating are segregated depending on the position of the knife in the

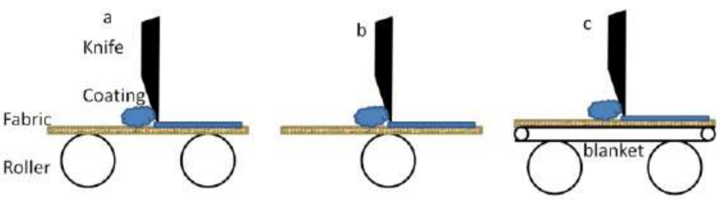

Figure 2. Knife coating, a) Floating knife, b) Knife over roller, c) Knife over the blanket

a. Floating knife- in this, the knife is positioned over the fabric. The thickness of the coating is controlled by fabric tension and the depression of the knife. It is used to apply a relatively thin coating.
b. Knife over roller- in this, the knife is suspended over the roller and does not touch the fabric. The distance between the fabric and the knife can be set to get the required thickness of the coating.
c. Knife over blanket or conveyer- this type of coating is mostly used to coat delicate fabrics.

In knife coating, penetration of the coating into the substrate and the amount of coating applied is influenced by the geometry of the knife, knife flexibility and rheology of the coating chemical.

4.0 Testing of adhesive-coated fabrics:

Testing of adhesive joints is carried out for a variety of reasons including but not limited to

1. Comparison of various properties such as tensile, shear, peel, environmental resistance, flexural, fatigue, impact, durability etc.
2. For performance and useful life prediction
3. Quality control between the batches
4. To check the effectiveness of surface treatment or surface preparation.

The major disadvantage of adhesive joints is that the interface area cannot be tested visually. It can be done in two ways by using destructive and non-destructive methods [14,16]. The list of various test methods used for the analysis of adhesive-coated fabrics are listed below. High adhesion strength is the primary requirement in all applications of coated fabric. The adhesion strength of the adhesive with the substrate can be tested using various methods. Here, only the peel test is discussed in detail as it is the most widely used for analyses of adhesive bonding strength.

4.1 Peel test:

It measures the force required to separate the adhesive layer from the adherend. This test is designed to use with flexible adhesives and it measures the highly localised stresses. The area over which the stress is applied depends on the thickness and modulus of an adhesive and the adherend. Therefore, it is difficult to evaluate exactly. Hence, it is measured as the force required per unit area for separation which is Pounds per linear inch or Newton per mm. In this type of T-peel test, all the applied load is transmitted to the bond and hence it gives the lowest peel value than any other type of peel test.[17].

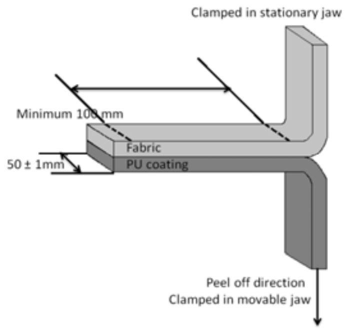

Figure 3: T-peel off test as per IS 7016-part 5

Figure 3 shows the testing of samples as per the standard test method described in IS 7016- part 5 for the determination of coating adhesion. There are other standard test methods also which include ASTM D1876-01, ASTM D903-98, ASTM-D751 etc.

- Apart from the adhesion strength of adhesive-coated fabrics other properties of the coated material are also important to measure. Those are listed below with standard test methods
- Coating mass per unit area IS 7016- part 1, BS 3424.
- Flexibility—Flat Loop Method (IS 7016 pt. 11 Based on ISO 5979-1982
- Stiffness of Fabric—Cantilever Test (IS 6490)
- Damage Due to Flexing (BS3424, IS 7016 pt. 4, ASTM D 2097
- Abrasion Resistance (ASTM D-3389, BS 3424)
- Water Vapor Permeability (ASTM E-96-80)
- Electrical Resistivity of Fabrics (AATCC 76-1995)
- Air Permeability (BS 3424)
- Tensile Strength ASTM D897-01, ASTM D5035
- Lifetime estimation and biodeterioration by thermo gravimetric analysis

5.0 Review of plasma treatments of textiles for adhesion improvement:

The term "Adhesion" is broadly used for bonding polymer-to-metal adhesion, cell adhesion in biology or the medical field, polymer composite adhesion, polymer-to-polymer adhesion etc. which practically include all types of materials and adhesives. A huge amount of research work has been done in each area therefore it is not possible to refer to all those works also not in the scope of the current review. Therefore, a review of the adhesion of textile fabrics with coating chemicals and plasma treatment is given.

Plasma interactions with the material surface result in physical and chemical modification like surface cleaning and roughness, formation of chemically reactive groups, improvement hydrophilicity etc. These modifications of the surface are mainly responsible for the improvement in adhesion bonding in the following ways

a. Cleaning of the surface removes the weak boundary lays (WBL) which are mainly responsible for lower adhesion

b. Surface roughness provides more interlocking points over the surface and improves mechanical bonding. Also, it results in an increased contact area between the fabric surface and adhesive.

c. The formation of chemically reactive groups gives rise to the formation of covalent bonds and is known to yield the strongest bond. This works on the adhesion theory of chemical bonding.

d. The adhesion theory of adsorption and wetting works well when the surface of the material is hydrophilic. The improved hydrophilicity after plasma results in better wetting and spreading of chemicals over the surface providing intimate contact between the adhesive and adherend [18,22] .

R. R. Deshmukh et al [23] have reported the effect of air plasma treatment on PET film for adhesion and printability improvement. Plasma treatment of PET was performed for 15sec to 30min and the T-peel strength of the samples was studied as a function of adhesion. An increase in adhesion strength with increased treatment time is reported. Improved adhesion after plasma exposure was attributed to surface roughness and increased surface energy. Further, it was reported that the formation of polar groups such as –CO-, -COO-, -OH is also responsible for improved adhesion. Similarly, adhesion properties of DC plasma-treated PP and PET film were studied by K. Navaneetha Pandiyaraj et al [24] who reported the enhanced adhesion with scotch tape by T-peel method and mentioned that mechanical interlocking is the key factor for improved adhesion. The same author with co-workers has also reported the adhesion improvement after DC glow, vacuum, atmospheric pressure, non- thermal plasma treatment for LDPE, PE and PP polymer films [25-30]. Improved bonding between henequen fibres and high-density polyethene (HDPE) by ethylene plasma treatment is reported. The interfacial shear strength (IFSS) was measured by a single fibre pull-out test. SEM and FTIR techniques were used to study surface morphology and chemical changes in the fibre. Increased IFSS is due to mechanical interlocking and chemical bonding is attributed to increased surface roughness and possible reaction with vinyl groups[31].

M J Shenton et. al.[32] have treated the low-density polyethylene (LDPE) and poly(ethylene terephthalate) (PET) by atmospheric and vacuum plasma using air, nitrogen and helium gases for the adhesion improvement with epoxy resin. A 180° peel test was employed to study the adhesion behaviour of the samples. It was reported that PET has better adhesion with epoxy than LDPE as PET contains oxygen in its chemical structure. Further, it was reported that atmospheric pressure plasma rapidly imparts the adhesion by a factor of two to ten; however, longer atmospheric plasma treatment does not improve the adhesion as the surface is ablated. On the contrary, LDPE and PET treated for a longer duration in vacuum plasma showed improved adhesion. Improved adhesion to LDPE for automotive applications is also reported [33] effect of helium–air atmospheric pressure plasma on adhesion between the aramid fibre and epoxy resin was studied by micro bond test. 109% increase in interfacial shear strength after the 60s of plasma exposure is reported also 16-26% increase in single fibre strength was observed[34].

Rachel M. Thurston et al [35] have treated Polyethylene and polystyrene at near-ambient temperatures using atmospheric plasma and studied the adhesion with three commercially available adhesive systems. It was reported that the improvement of adhesion is mainly due to increased surface energy and improved wetting characteristics. The effect of low and atmospheric pressure plasma on adhesion with various adhesives on almost all kinds of fibre has been reported by several researchers[35-46] .

It is well known that plasma surface modification of polymer decay with time and molecular chain re-agreement taking place with long storage time is known as ageing of the polymer. D. J. Upadhyay et al [47] have studied the plasma polymerisation of dichloromethane(CH_2Cl_2) on PP film for adhesion improvement with the commercially available adhesive tape and ageing properties were studied. They found that adhesion strength (measured by T-peel) increased with increased plasma exposure time. Further, there was a minimum change in the peel bond strength of CH_2Cl_2 plasma polymerised PP film after 2 months of ageing. N.V. Bhat et al, [48] have reported the acetone (AC) and acetone/oxygen (AC/O_2) plasma surface modification of PP film for adhesion improvement and the effect of aging on adhesion strength. They found that the surface energy of the plasma-treated film by AC and AC/O_2 has been significantly improved. Adhesion of AC-treated PP film improved but AC/O_2-treated samples showed a negative effect on adhesion initially. After aging adhesion strength moved from negative to positive for AC/O_2-treated PP film and no change in adhesion was found for AC-treated film after aging.

An interesting study was conducted on the effect of DC glow and microwave plasma treatment on adhesion of PMMA samples. Authors have found that both types of plasma treatment result in an increase in the surface energy of PMMA, however, only DC glow plasma treatment could result in improved adhesion to evaporated inorganic coatings on PMMA. Therefore, it was concluded that increased adhesion is much more determined by surface modification than only increased surface energy[49].

The adhesion of textile materials to rubber is widely studied for application in tire cords. E. L. Lawton [50] has treated the polyester multifilament 2000 denier cored with low-temperature plasma using gases such as argon, nitrogen, helium, carbon dioxide, oxygen, hydrogen, ammonia and propane. The plasma-treated PET cord was coated with resorcinol formaldehyde-latex (RFL) and adhesion strength was studied. The author found that plasma processing parameters vis type of gas, exposure time, power level, and pressure were insensitive to adhesion improvement. However, the improvement of adhesion was found with adhesive curing conditions, conditions of bonding tests and rubber composition. On the contrary, H Krump et al [51] have shown that adhesion of PET fibres with rubber matrix is positively affected by the type of plasma gas used. In another study, polyester multi-cord sewing threads were treated with barrier discharge, atmospheric pressure glow discharge and gliding arc. Adhesion properties with the rubber matrix were studied by H-test and Peel test. The best improvement was found with nitrogen gas by atmospheric pressure plasma [52]. Atmospheric pressure plasma treatment on the polyester cord and ultrahigh molecular weight polypropylene (UHMWPP) for adhesion improvement with rubber matrix have also been reported [53,54].

The effect of atmospheric air plasma treatment with respect to adhesion with silicon resin on different structures of polyester vis film, woven and non-woven fabrics have been studied and reported that the adhesion is influenced by the structure of textiles in addition to plasma treatment .

Recently, S. Palaskar et al have reported the effect of atmospheric plasma treatment on different textile structures and found the dependency of plasma processing with various GSM, Weave patterns and fabric constructions [56,57].

6.0 Summary:

Adhesion is often misunderstood with cohesion, the difference between the two is discussed in detail. A total of six theories of adhesion are reviewed. Types of coating techniques, testing of coated materials and application of plasma technology for adhesion improvement are reviewed. Plasma interactions with the material surface result in physical and chemical modification like surface cleaning and roughness, formation of chemically reactive groups, improvement hydrophilicity etc. These modifications of the surface are mainly responsible for the improvement in adhesion bonding and different mechanisms of adhesion work together.

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Textile Processing Water Conservation - a case study

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Abstract
To control the production cost, utility (water, steam and power) cost control is required and important. In a well-disciplined organisation, the utility cost to produce 1 kg of the textile should be properly monitored and controlled as per proposed benchmark standards. Among these three utilities, water is a very important utility as it is impacting on the production cost as well as the environment also. To optimize water consumption and hence effluent generation, the water conservation audit in the process house is a required and recommended activity. In this paper, a case study of a water conservation audit in one of the textile woven processing units is discussed with facts and figures based on the actual production data. The illustration of water monitoring and preparing a water balance, estimation of processes water consumption and machine/process is a wise effluent generation with opportunities for hot water recycling to reduce the water footprint is discussed in the paper. As an audit outcome, at least a 15% reduction in the water footprint in the process house was found to be possible. Textile processing mills can avail of this BTRA expert services for their unit.

Key words:
Water conservation, Textile processing, Recycling and reuse, Effluent, CRP, Water footprint, Steam

Citation
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1.0 Introduction

The four types of utilities i.e. water, steam, air and electricity are consumed while textile processing production and these utilities have their magnitude of impact on production costing, the environment, carbon footprint and pollution. Here, water as a utility is considered for conservation study. Water consumption is affecting production costing, and aquatic pollution and is indirectly related to fuel costing also. The more the water consumption the more will steam and hence fuel consumption accordingly, and thus the water consumption i.e. water footprint is contributing to the increase of the carbon footprint also. To reduce the water footprint, every textile process house should think and act for water saving wherever possible. Water saving is one aspect of water conservation. In totality, water conservation is the practice of making and understanding the total water balance, using water efficiently to reduce unnecessary water usage and wastage, finding the opportunity for maximum recycling of cold and hot water, reuse of the less contaminated water in the process again etc. So, to do this, the management should have a clear focus, actions and systems for

- Making and understanding the water balance
- Estimation of the water consumption for various machines processes and activities
- Estimation of evaporation losses during the process
- Estimation of effluent generation
- Maximum possible recycling and reuse

The BTRA Mumbai is involved in water conservation audits for textile processing units. This ent paper deals with the audit outcome of one of the fabric processing units. The savings effort made by the process house and further potential saving scope are discussed in this paper. This study outcome will be a guideline for other units. The information shared here may not fit as it is to all the textile process houses. The audit outcome will be depending upon their product mix, water input source, processing machine automation and set-up, process routes followed, work culture, customer quality requirements and type of effluent treatment plant and automation done on the machines.

Thus audit outcomes may vary from plant to plant. We suggest every textile process house should do this activity for business sustainability and cost control. The BTRA Mumbai is actively doing the water conservation audits of the process houses with the help of shopfloor experienced and qualified team of technicians.

In the present paper following aspects are discussed;

- Current water balance
- Monthly specific water consumption data
- Estimation of water consumption processes
- Estimation of water evaporation – processes

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- Estimation of effluent generation
- Hot water generation and potential consumption areas
- Water monitoring status and expectations
- Leakages and wastages

2.0 Current water balance

Water balance is the accounting of the water withdrawal from different input sources, water consumption for process house, boiler and domestic use, recycling of non-contact water, recycling of process water after RO treatment, evaporation losses and discharging of wastewater. A water balance helps you to understand and manage water and effluent efficiently, identify the areas with the greatest opportunities for cost savings, and detect leaks. The water balance for the processing unit under study is given in the below Table no. 1

Table 1 – The water balance for the processing unit

Sr. No.	Details	Quantity (KLD)
Water Source		
1	Industrial District corporation intake	3320
2	Borewell water (Max discharge 10 KL/HR)	100
3	Rainwater Harvesting	70
4	Recovered (RO recycle + steam condensates from MEE, CRP + machines)	2780
	Total	**6270**
Consumption		
1	Domestic use	310
2	Process house (fabric processing)	**4680**
3	Weaving	120
4	Made-ups	50
5	Boiler (Steam Condensate + RO recovered)	**820**
6	ETP	40
7	Gardening	250
	Total water consumption	**6270**
Effluent Generation		
	Coloured / Non -coloured	**5200**
Discharge		
1	Coloured / Non -Coloured after treatment to CETP	**2420**
Recycle		
1	RO Recovered	2120
2	MEE Recovered	180
3	Machine condensate	130
4	CRP condensate recovery	350
	Total	**2780**
Losses		
1	Process Loss	400
2	Domestic Loss (canteen + domestic use+ gardening)	270
3	Other Losses	400
	Total	**1070**

Note:- KLD means Kilo litres per day

The above water balance shows that major water consumption is at fabric wet processing and then for steam generation boiler. About 45 % of water is recovered, recycled and reused in the process house again and freshwater demand is about 55 %. The freshwater demand can be further reduced by increasing recycling through RO and steam /vapour condensates.

3.0 Monthly specific water consumption Data

The fabric production data for the period of April 2021 to Sept 2021 was analysed for total plant water footprint and processing water footprints as given in table 2. On average 53.9 litres of water is consumed for fabric processing and overall factory operations 80.8 litres of the fabric is consumed per kg of the fabric finished.

Table 2:- Overall plant and fabric processing water footprint

Month	Production in kg/month	Source (KL per month)	Consumption (KL per month)	Discharge (KL per month)	Specific water consumption for processing (Lit/kg)	Overall plant water footprint litres/kg
Apr-21	2474000	184700	129660	72800	52.4	74.7
May-21	2350000	198660	128540	73500	54.7	84.5
Jun-21	2293930	179860	127530	72100	55.6	78.4
Jul-21	1733300	176980	110750	71300	63.9	102.1
Aug-21	2412000	185760	119900	72600	49.7	77
Sep-21	2382200	176770	119320	70300	50.1	74.2
Total	**13645430**	**1102730**	**735700**	**432600**	**53.9**	**80.8**

To find out the water-saving opportunity areas, the process-wise water consumption data was estimated with the help of process knowledge/experience, process requirement, machine type, flow meter readings wherever available etc. Table no.3 shows the estimated water consumption for various wet processing machines.

Table 3:- Process-wise water footprint and benchmarking against BTRA standard [1]

Process	Water consumption	Benchmark water consumption
	Litres/kg	Litres/kg
Pretreatment	17-20	14-20
Dyeing by pad steam (CDR)	12-14	16-20
Dyeing by CPB and washing on the washer	25-26	15-20
Dyeing by pad dry and wash on washer 2	25-27	15-20
Printing	34-38	30 -45
Finishing	1-1.5	1- 1.5
Width stretch for printing	2-2.5	1- 1.5

Based on the above table and when comparing the present mill water consumption process-wise against BTRA Benchmarking norms, it was observed that the water consumption is under control except for the reactive dyed fabric washing on the washer. So, it is recommended to monitor the washing process more strictly for water metering(measurement) and leakages. During the audit, it was found that the leakages were more on the washer machine. Practically, it was observed that in both the washers, the water consumption was on the higher side i.e. 25-27 litres/kg of the fabric. The optimization of water consumption needs to be done at the washer through the correct monitoring and water inlet control and avoiding leakages. Also, the water consumption on the stenter for the width stretching process is on the higher side due to excess overflow from the padding trough.

4.0 Estimation of water losses:-

The water losses in the system are pertaining to evaporation losses during fabric drying, gardening water, water losses due to evaporation of the water from the floor, steam losses to the air, vapour losses from hot/boiling baths and all the heating baths etc. The following table gives the estimated quantification of the water losses in various forms. There is no flow meter generally used for water loss estimation. This has to be done on the basic process sequence followed, no time fabric dried, steam consumption, evaporation from a hot bath, steam condensation, process experience and engineering calculations. The below table no. 4 gives the estimated quantification of the water losses in the system. This also should be comparable with the difference between water consumption and effluent generation in the processes. In this case, major water losses are due to water evaporation in the drying process and gardening.

Table 4:- Estimated water losses:-

Water losses reason	Quantity KLD
Process loss - Water evaporation during the fabric drying	230
Process loss - Weaving and sizing	120
Canteen /domestic losses	20
Gardening	250
Other losses (floor water evaporation + excess steam losses to air, vapour losses from hot baths and other invisible losses etc)	400

3.0 Estimation of Effluent generation:-

While estimating the effluent generation quantities, all the possible sources should be considered. Here also, at each machine generally no flow meters are used at the drains. Hence, this estimation has to be done based on certain calculations and assumptions. This quantification is important because it will give an idea about the level of steam condensation, and pollution generated by each process and machine. The following table 5 gives the estimated data for the same based on a one-month production. Pad steam machine, Pretreatmentrange(PTR), pad steam, washing /soaper machine and printing colour kitchen are the major effluent generation processes.

Table 5:- Estimation of machines' effluent generation

Machine name	Avg Production	Estimated effluent generation
Unit-->	KG/Day	KLD
singeing quenching for machines 1 and 2	81000	100
PTR 1 and 2	81000	1020
Merceriser 1 and 2	50000	130
Pad Dry 1 and 2(Monforte)	22000	15
Pad steamer water seal water for machines 1 and 2	30100	280
Pad Steam 1 and 2	30100	480
Washers 1 and 2	22000	480
Jiggers and VDR	8010	155
Printing 1 and 2 with colour kitchen including engraving and washing	16500	320
All stenters finishing and width stretching	112000	65
Weaving and sizing	-	20
Made Up	700	60
Canteen and domestic water	-	290
CRP steam condensate, cooling water and vapour condensate	-	1400
softening plant backwash	-	120
Boiler blowdown	-	50
Leakage and others	-	130
Total Effluent generation in KLD		**5115**

6.0 Hot water generation and reuse possibility in the plant

During the water conservation audit, the hot water generation points were detected/identified and based on the water temperature and quality, the possibility of reuse of the same was thought and accordingly the suggestions for reuse were given. The below table no. 6 gives the quantification of the hot water generation and its current status in the mill.

Table 5:- Estimation of machines' effluent generation

Sr. no.	Hot water generation point/ activity	Appr. flow rate KLD	Temp. range °C	Status
1	CRP steam Condensate	90	90-95	Drained to Gutter and ETP
2	CRP vapour condensate	310	60-70	Drained to Gutter and ETP
3	CRP cooling water	1000	50-60	Drained to Gutter and ETP
4	Jiggers power pack cooling water	180	40-45	Recycled
5	Singeing burner cooling water	100	45-50	Recycled
6	AC panel cooling water	990	40-45	Recycled
7	VDR cooling cylinders water	810	40-45	Recycled
8	Sanforize rubber cooling water	100	40-4s	Recycled

From the above table, it is clear that reusable hot water is about 1400 KLD. From this 1400 KLD, steam condensate water can be used for boiler feed water. CRP vapour condensate and cooling water can be reused for mercerised, PTR and soaper machines. As estimated, the hot water demand from these machines is 1360 KLD. As per audit findings, at present about 200 KLD of hot water was being reused. So, there is a scope of 1160 KLD hot water for use at these machines. The potential steam saving by implementing this will be 45 tons per day and in terms of Rupees, it will be Rs. 112500 per day (at the rate of steam generation costing of Rs 2.5 per kg). In addition to this, by implementing this hot water reuse, the water footprint can be reduced by at least 15%

Requirements for the above implementation:-

i) We recommend installing an online condensate contamination detection system so that CRP cooling water, as well as vapour condensate, can be monitored for pH and TDS. This demands high-level maintenance of the CRP unit to avoid the carryover of caustic lye traces. Also, periodically once in a shift the TDS, pH along with iron contamination should be verified manually and maintain the record for the same. This will avoid the chances of the use of contaminated water and fear of the same.

ii) The level control system working on the hot water tank should be ensured with updated logic and sensors so that an uninterrupted water supply will be there to the process house either hot or cold through the same valve system to the machines. This is for avoiding valve operations change manually when hot water (vapour cooling water and condensate water) is not available.

7.0 Water monitoring system and requirements

Monitoring and measurement are the two most important aspects of ineffective industrial water management. if you cannot measure it, you cannot conserve it. You can't manage what you don't measure.

Metering here refers to measuring water flow rates and quantities at various points of use. These readings of water measurement at various points can be developed into a database or water record of a particular premise or industry or process. Most of the machines were found to be equipped with the metering system in place. The details are given in table no. 7. For the machines as well as water-intensive areas where there is no measurement, the BTRA audit team suggests implementing a metering system for proper quantification.

Table 7:- Status of the water metering system:-

No.	Department	Machine name	Water in Flowmeter availability (Yes/no)
1	Pre-treatment	PTR 1 and 2	Yes (on the machine)
		Mercerizer 1 and 2	Yes (on the machine)
2	Dyeing	Pad-steam –1 and 2	Yes (on the machine)
		Pad-dry 1 and 2	Yes (on the machine)
		Washer -1 and 2	Yes (on the machine)
		Colour kitchen	No
3	Printing	Printing 1 and 2	Yes (on the waterline)
		Colour kitchen	No
4	Finishing	Stenters (for washing)	No
		Chemical preparation	No
5	Weaving	Sizing department	No
		Compressor cooling	Yes (on the waterline)
6	Made-ups and washing		No
7	Gardening		No
8	Boiler feed water		Yes

The above listing can be further expanded as areas other than processing are considered. It is recommended that every consumption point should have a water metering system.

8.0 Leakages and wastages

During the study of water conservation at the following point leakages and water wastages were observed by the BTRA team

- Leakage was observed in both the Pretreatment range at water line joints
- Water leakage from the water seal of both pad steam unit
- Washer machine leakages at the joint of the washing compartment
- Through leakages at the washer machine
- Jigger machine through leakages
- Mercerizer washer bearing seal leakage
- Eye washer leakage in the chemical store
- Printing colour kitchen auxiliary pipe valve leakage (continuously flowing)

9.0 Conclusion

To understand and estimate the overall processing water footprint per kg of the fabric a comparison against the proposed benchmark water conservation audit was conducted. It was a systematic attempt to find out the water wastages/ leakages areas, water consumption pattern process-wise and machines, estimation of water losses in the system, estimation of processes machines effluent generation, the water recycling possibilities in the system based on the water quality requirement, hot water generation and reuse possibilities in the process house and estimation of possible steam saving. Steam savings of at least 3 Cr were possible by implementing the suggestions in the report.

In general, depending on a plant's work culture, product mix, types of processes, process routes, machinery types and automation, Water flow rates in the washing compartment, M:L ratio, proper planning at washing machine, present water consumption level and effluent treatment plant and recycling capacity etc, the scope for water saving varies.

The BTRA Mumbai is having the required expertise for conducting water conservation and also energy audits. The mill may contact an email 'tsd@btraindia.com' for the same.

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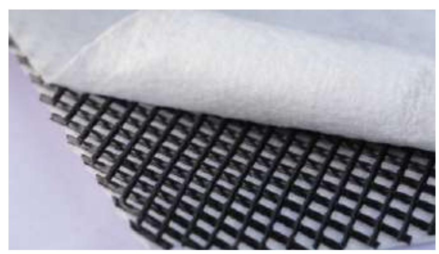

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