Kurita Dropwise Condensation technology application for improving heat transfer efficiency in paper drying machines

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KEYWORDS: Efficiency, condensation, heat transfer, hydrophobic, film-forming substance, hydrophobicity, heat transfer efficiency, steam consumption

ABSTRACT

The drying process in paper industry is the process that allow the removal of the water for giving the final properties to the product. At the same time, it is one of the most intensive energy consumers in the paper production process.

Therefore, the efficiency of the drying section makes a big influence in the overall economic figures, as well as in the product quality. It is critical to keep efficient heat transfer conditions in each of the cylinders. This heat transfer is determinate by the condensate removal, and the surface properties in terms of corrosion and scaling.

Thanks to many years of experience and knowledge in film-forming technologies, Kurita has developed Kurita Dropwise Technology which improves productivity and boosts heat transfer efficiency in paper dryers by the creation of a hydrophobic layer that not only protects the system from corrosion and scaling, but also avoids the formation of a condensate film in the inner surface of the rotating cylinder thanks to the dropwise condensation effect that makes the water droplets to flow down from the surface as soon as they condense.
The removing of the condensate layer increases the heat flow up to a 30% improving the efficiency of the whole system.

Kurita Dropwise sustainable technology leads to a reduction of carbon dioxide emission supporting the development of an eco-friendly society. That is one of the reasons why it has been awarded by the Agency of Natural Resources and Energy in the Product and Business Model category of the 2019 Energy Conservation Grand Prize organized by The Energy Conservation Center, Japan.

Key words: Efficiency, condensation, heat transfer, hydrophobic.

INTRODUCTION

Kurita Dropwise Condensation Technology is a product based in film forming substances used for condensing efficiency improvement in industrial systems, which aims at improving heat transfer by changing the condensing mechanism from film wise condensation to dropwise condensation, this is allowed by the creation of a film forming substance based hydrophobic film in the condensing surfaces.

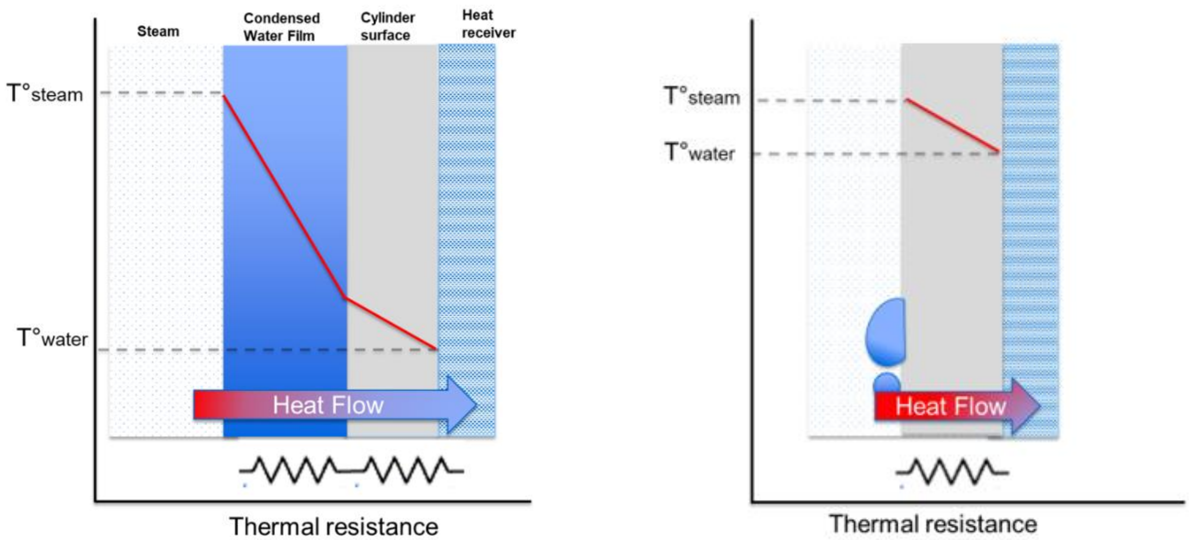

Figure 1 Thermal resistance with and without water condensation film

1.1.1. Film wise condensation:

Unless specially treated, most materials are wettable, and condensation happen in the form of a film of condensate that spreads over the surface. The rate of condensation, the viscosity of the condensate and whether the surface is horizontal or vertical are some of the parameters that affect the thickness of this layer.

Fresh steam condenses on to the outside of the film & heat is transferred by convection instead of conduction through the film to the metal surface. This heat flow through the film, like all energy exchange, is associated with losses.

This film of liquid act as a barrier to transfer of the heat and its resistance accounts for most of the difference between the effectiveness of film wise and dropwise condensation.

As the film thickness it flows downward & drips from the low points leaving the film intact and at an equilibrium thickness.

Due to the nature of the materials used in the construction of condensing heat exchangers, film wise condensation is normal.

1.1.2. Dropwise condensation:

Kurita Dropwise Technology treatment of the condensing surface creates a hydrophobic layer, based on a monomolecular film which change the contact angle & the surface become 'non – wettable'.

This means that as the steam condenses, a large number of generally spherical beads cover the surface. As the condensation proceeds, the bead become larger, coalesce, and fall over the surface.

The clean/dry surface offers very little resistance to the transfer of heat and very high heat fluxes are possible.

Although many metal surfaces are 'non-wettable' this not the case of the oxide film which quickly covers the bare material, that is also removed thanks to Dropwise Technology treatment.

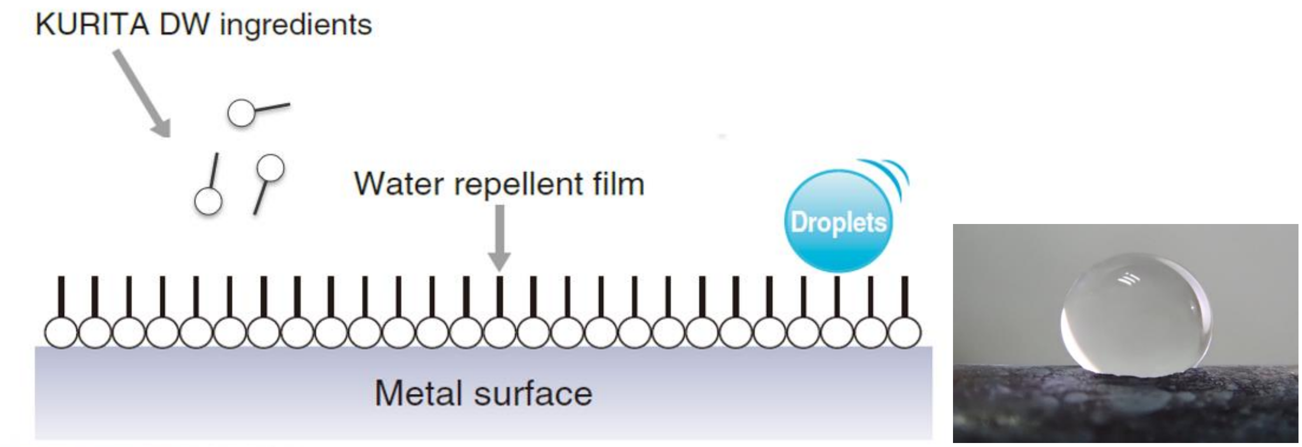

Figure 2 Hydrophobic film formation mechanism and contact angle of a water drop on a treated surface

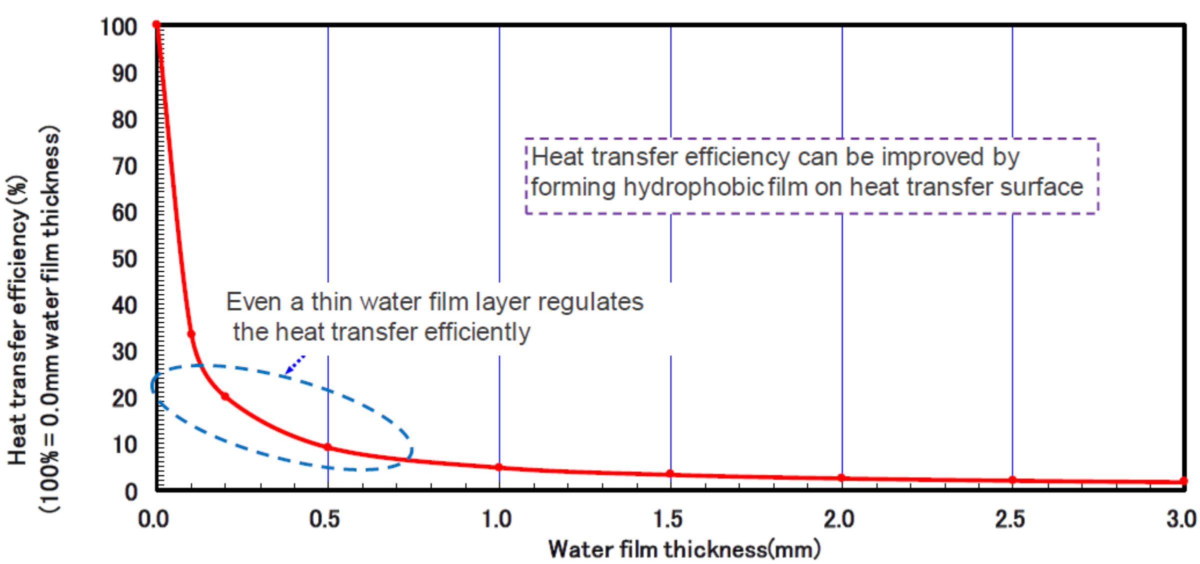

Figure 3 Heat transfer efficiency in % vs water film thickness

Figure 3 shows the relationship between the water film thickness and the heat transfer coefficient calculation. The heat transfer coefficient drops to 10% even if there is a water film with a thickness of only 0.5 mm generated on the surface. So that heat transfer efficiency can be improved x10 with the hydrophobic film on the heat transfer surface created by Dropwise.

Kurita Dropwise Condensation Technology consists of a service based on continuous dosing of the product in the steam line prior to the target device.
The target device is always a condensing system.
In paper drying machines it is dosed before the rolls, allowing the film to form gradually.
It is a dynamic film, i.e. it is continuously being lost and replaced.
In Dropwise Condensation Technology projects, the residual product in the condensate is measured, thus verifying that the film is formed. In turn, Kurita includes in its service the monitoring of the operating parameters powered by Dropwise, so that the customer can see the results of the treatment.
In addition, Kurita provides sampling methods that allow to verify the existence of the film on the surfaces during an inspection.

The treatment does not affect process water quality, has no significant effect on condensate pH or conductivity, and is compatible with traditional boiler water treatments.

EXPERIMENTAL PROCEDURE EVALUATION OF HEAT TRANSFER COEFFICIENT

The heat transfer coefficient was evaluated by using the overall heat transfer coefficient. The Uvalue, which is the indicator of heat transfer speed, is defined as follows.

$$\mathrm{U} = \frac{1}{R_T} = \frac{1}{R_{se} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots + R_{si}}$$

U: heat transfer coefficient in W/(K・m^2)

R_T: thermal resistance in (K・m^2) / W

R_{se}: external heat transfer resistance in (K・m^2) / W

d_i : thickness of the layer number i in m

λ_i : specific thermal conductivity of this layer in W / (K・m)

$1/R_\lambda$= lambda..sub.i,i : the specific heat resistance of the i-th layer in (K・m) / W

$d_i/$.lambda..sub.i = $_{\mathrm{R}}i$: the thermal resistance of this layer in (K・m^2) / W

R_{si}: internal heat transfer resistance in (K・m^2) / W

The U value is opposite to the thermal resistance and is defined as the amount of heat that flow through a surface per unit of time, is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The larger the coefficient, the easier heat is transferred from its source to the product being heated. In a heat exchange, the relationship between the overall heat transfer coefficient (U) and the heat transfer rate (Q) can be demonstrated by the following equation:

The U value was calculated by the following equation, measuring inlet and outlet temperatures

$$\dot{Q} = U * A * \Delta TLM$$

of cooling water and steam

Q = heat transfer rate, W=J/s [btu/hr]

A = heat transfer surface area, m2 [ft2]

U = overall heat transfer coefficient, W/(m2°C) [Btu/(hr-ft2°F)]

ΔTLM = logarithmic mean temperature difference, °C [°F]

Figure 4 shows the schematic of the test equipment to measure the U value. The equipment used was a shell and tube type heat exchanger constructed of all stainless-steel components except forthe the heat exchange tube, which was made of copper. The heat exchange tube's outer diameter φ is19 mm, the inner diameter is 17 mm, and the length is 1,500 mm. So, the heat transfer area is 0.09 m^2. Kurita Dropwise condensation technology was added at 20 mg/kg to the steam generated at the pressure of 0.7MPa.

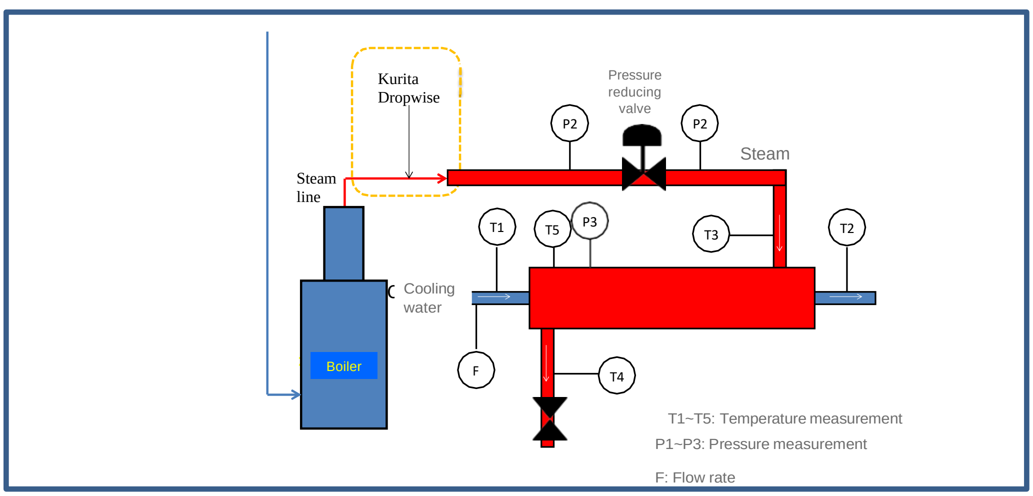

Figure 4 Scheme of laboratory equipment for U value determination

RESULTS AND DISCUSSION EVALUATION OF HEAT

TRANSFER COEFFICIENT

Figure 5 shows the behavior of the U value when Kurita Dropwise Condensation Technology was dosed just prior tothe heat exchanger. DW Index is the indicator of residual product in the condensate water. Kurita Dropwise started dosing from day 2, and then the U value was increased gradually until day 9.

Finally, the U value was improved by about 30% with the application of Kurita Dropwise Technology.

On day13, we stopped dosing Kurita Dropwise and the DW Index was not detected on day 14. The U value was kept at the same level in spite of not being injected with the product for a week.

During this period, no residual concentration was detected. On day 20, the U value dropped suddenly. These results follow Kurita Dropwise condensation technology effectiveness against single FAC test results, which also showed a protection for more than one week without Kurita Dropwise condensation technology dosage and no residual of the product in the water phase. Under both conditions Kurita Dropwise condensation technology film apparently was stable for more than a weekafter discontinuing the product dosing.

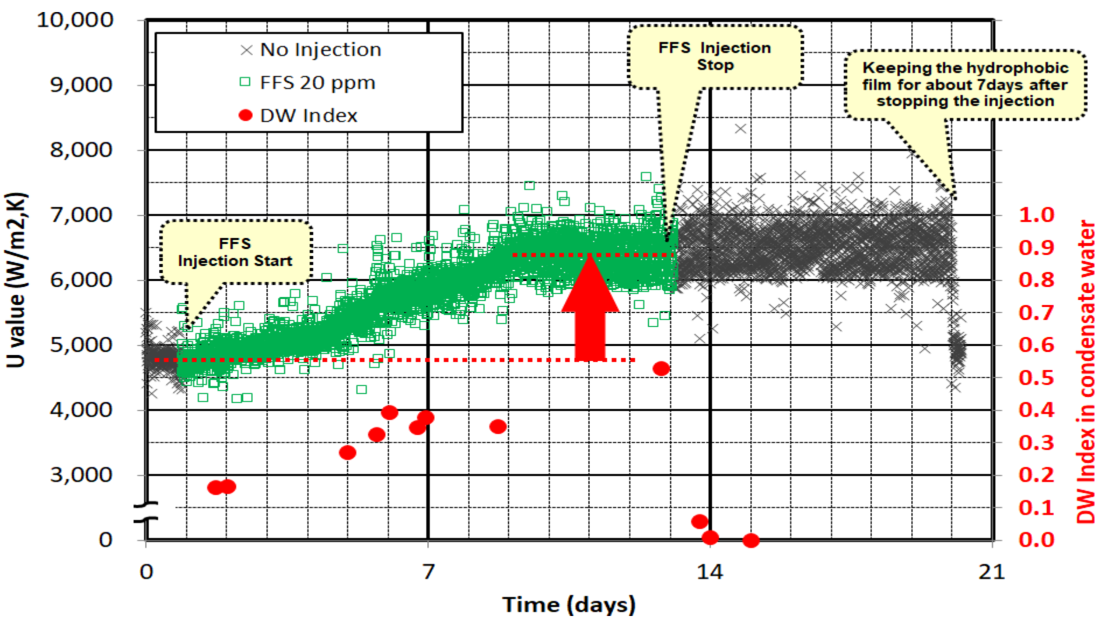

Figure 5 U value improvement thanks to Kurita Dropwise application

After confirming the effectiveness of Kurita Dropwise for improving heat transfer in the lab, we proceeded with verification on industrial paper machines

FIELD EVALUATION

The image of a multicylinder dryer machine in a pulp and paper factory is shown in the following figure. The paper dryer section is the portion of this process where the remaining water is evaporated by the heat energy supply.

Between 1,1 and 1,3 kg of steam are removed per kg of paper, and that's the reason why this part of the process is the greatest energy consumer of the process (around 40% energy consumption of the overall process)

In a typical dryer system, the paper web is led over dryers that are heated from the inside by means of steam. This section of the paper mill is where most of the energy consumption takes place. Rotating cylinders are heated to remove residual moisture, and at the end, the paper only holds less than 10 % of residual water. Here Kurita Dropwise Condensation Technology dosed directly into the steam line prior to the dryer section creates a water repellent film on the internal surface of the rotating cylinders. This leads to improved heat transfer and a significant reduction in steam consumption.

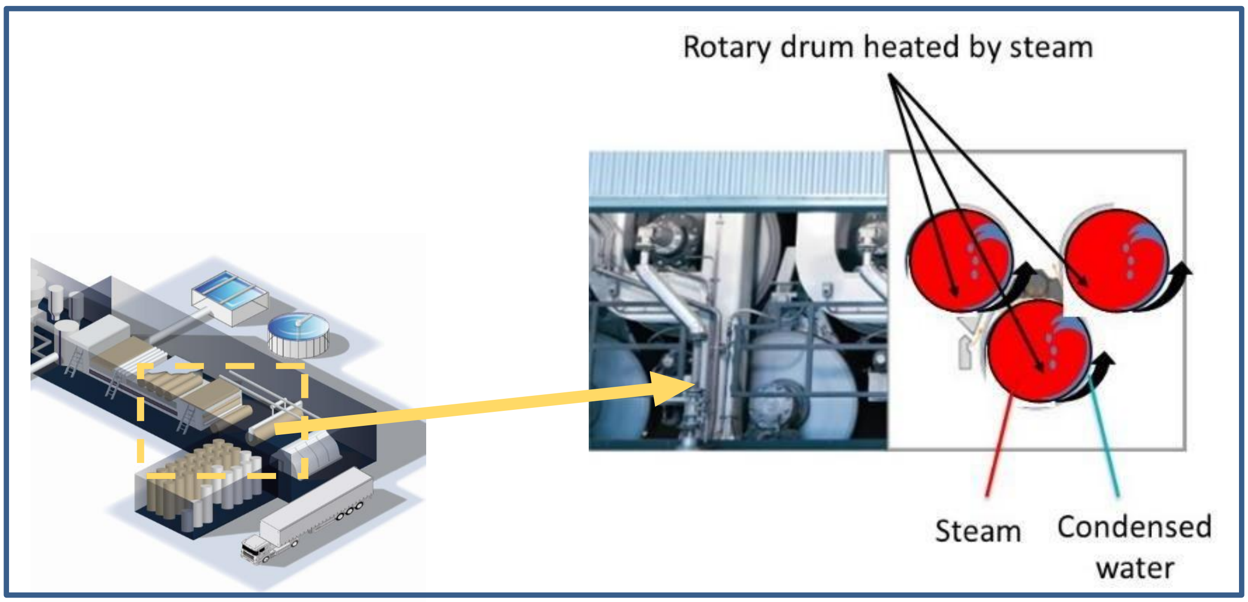

Figure 6 Scheme of dryer section in paper industry. Multicylinder machine

The data is collected during 6 months of dosing and compared with the average for the same period of the previous three years to avoid seasonal interferences:

- Cylinder surface temperature
- Steam consumption
- Paper production of the different grammages in tons.
- Moisture content

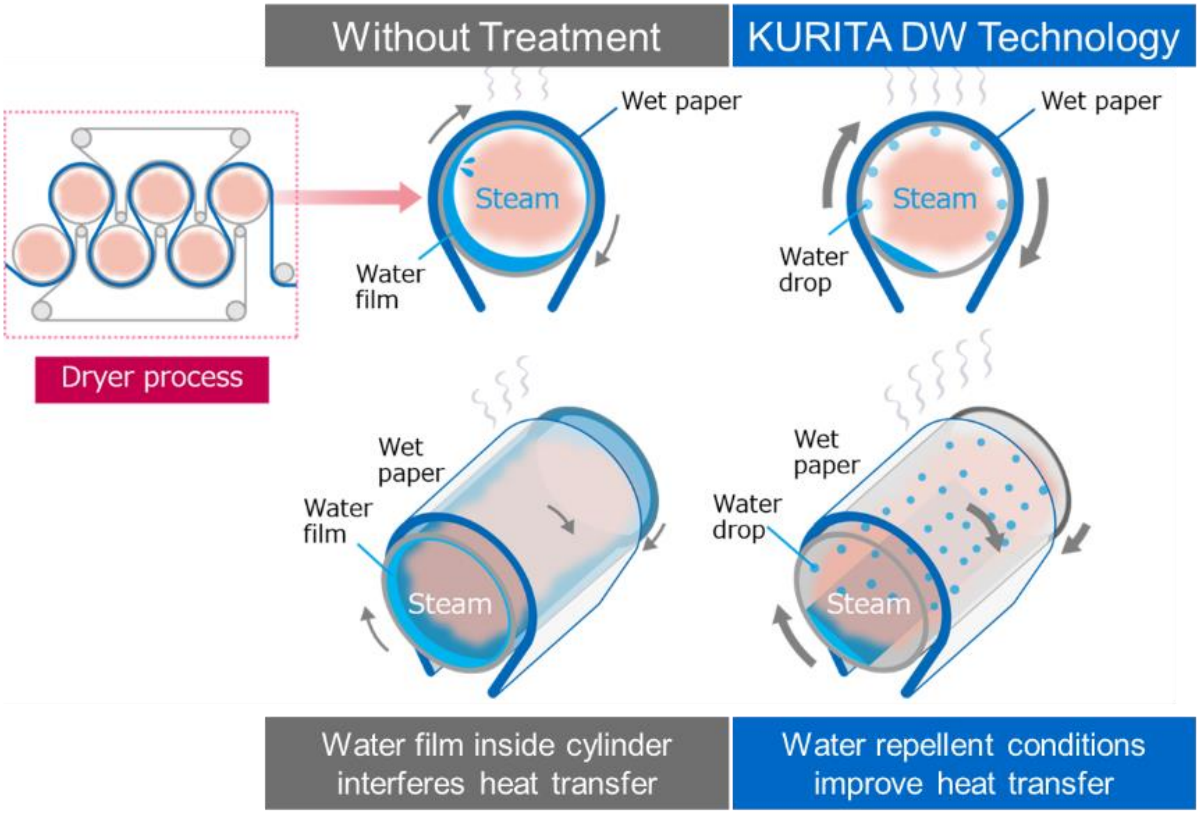

Figure 7 Dropwise effect in drying cylinders

Industrial Application 1

This factory is located in Europe and produces filter paper.
The dryer section is a multicylinder machine with the following characteristics.

12 dryers:

- System pressure 3 bar
- Set humidity point 3%
- Dryer speed: 450 m/min

In blue : Before Kurita Dropwise Condensation Technology Application
In purple: After Kurita Dropwise Condensation Technology Application

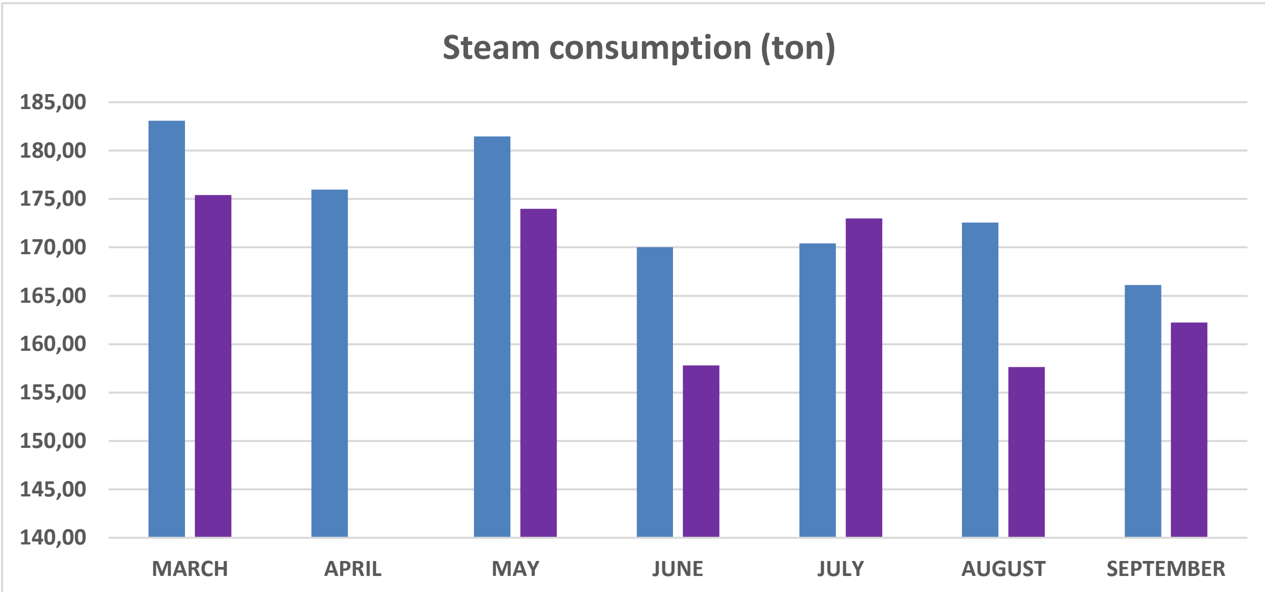

Figure 8 Steam consumption evolution before and after Kurita Dropwise Technology application

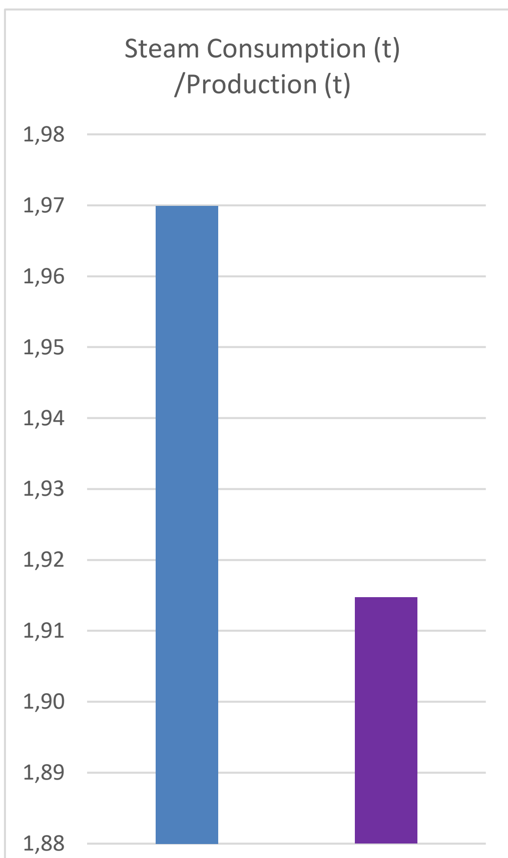

Figure 9: Steam consumption in tons per ton of paper produced

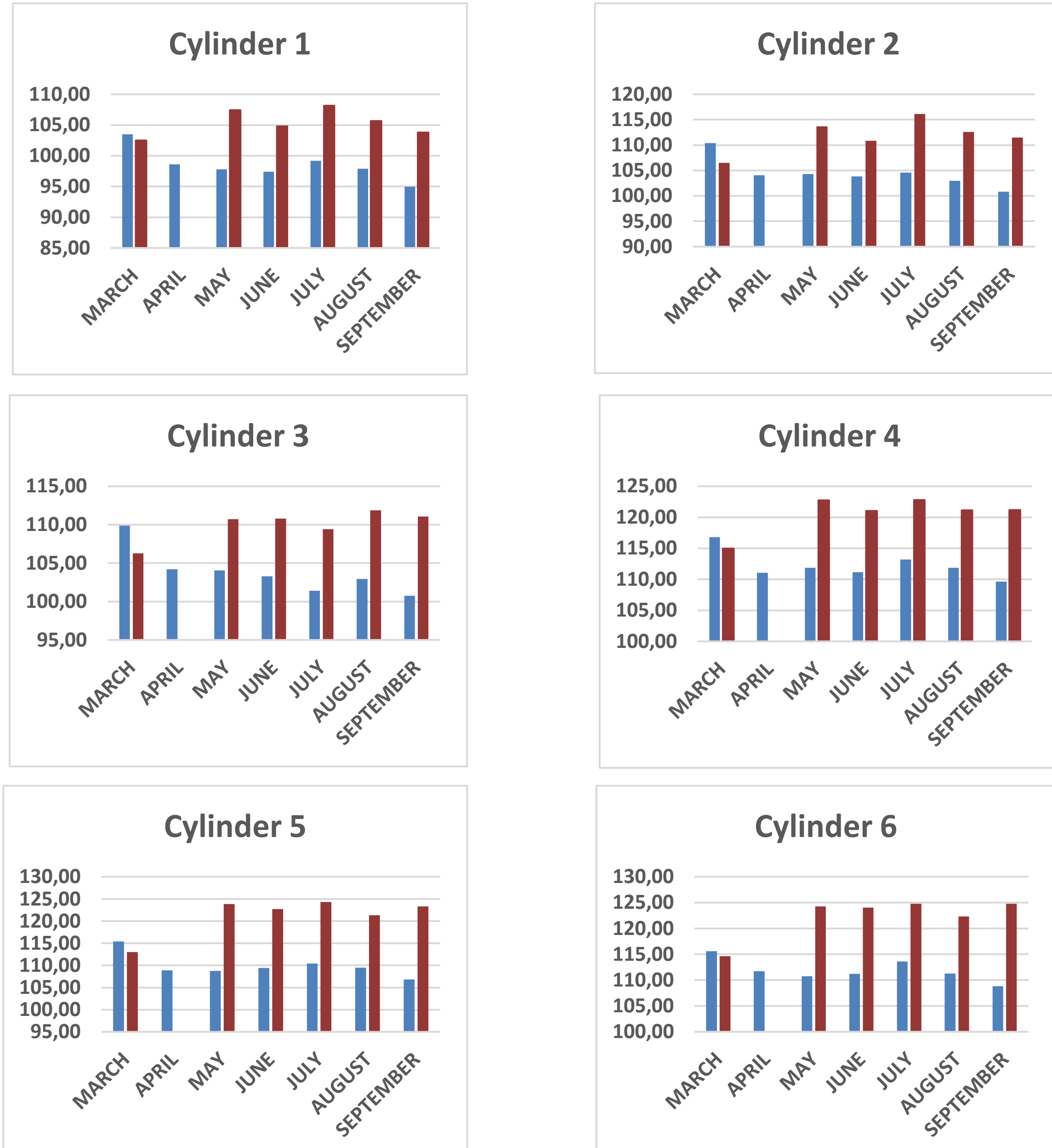

Figure 10: Cylinder surface temperature compression before and after Kurita Dropwise Condensation Technology application

Although the customer used 4,5% less steam in average, the average temperature of the cylinders was 7,7% higher.

The ratio Steam consumption per ton of steam was reduced by 4%.

This allowed the customer to save 127.000 €/year by reducing fuel consumption, CO_2 and water costs.

Industrial Application 2

The second example of an industrial application is a board and packaging paper mill with the following characteristics:

52 dryers:

- 32 High pressure dryers: Inlet pressure 4 kg/cm^2 - outlet pressure 3,6 Kg/ cm^2
- 14 medium pressure dryers: Inlet 3,6 kg/ cm^2 – outlet 3,2 Kg/ cm^2
- 6 low pressure dryers: inlet 3,2 kg/ cm^2 – 2,8 kg/ cm^2
- 0,35 bar differential pressure.

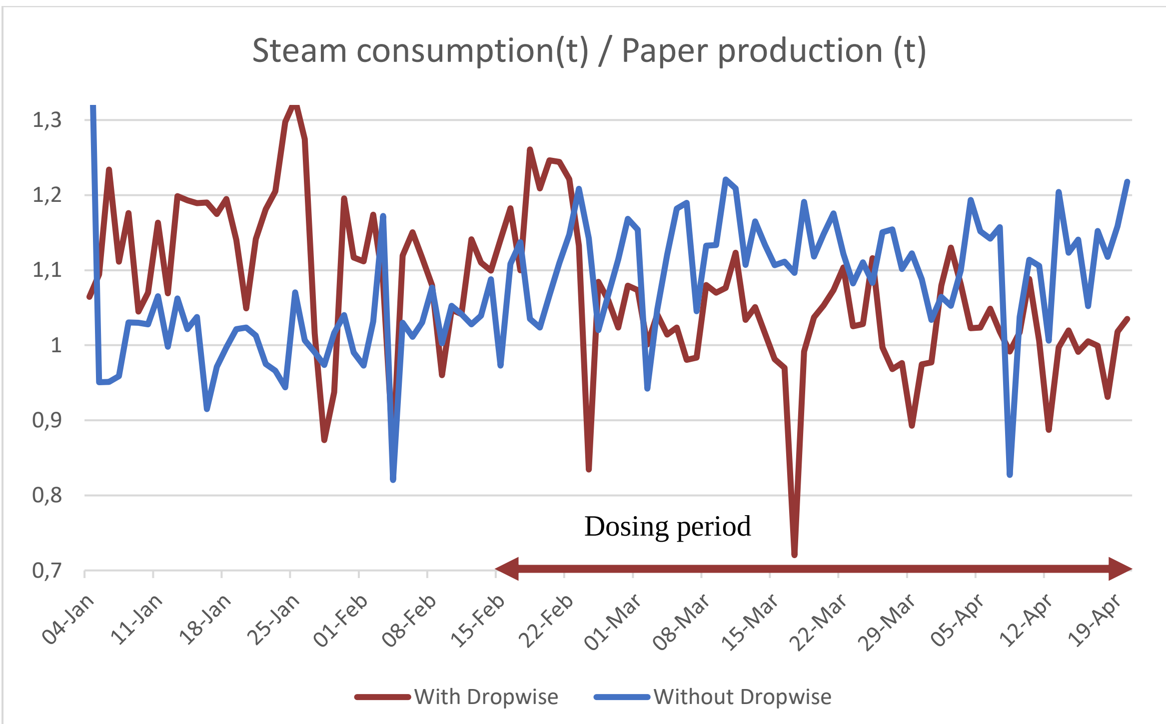

Figure 11. Steam consumption evolution before and after Kurita Dropwise technology application.

In this application the steam consumption per ton of paper was reduced by 6% bringing economic savings of 205.000€ considering reduction of fuel, water and CO_2 emissions.

Industrial Application 3

The second case study was conducted at a tissue paper factory with the Yankee dryer. Between 2013 and 2015 the consumption of steam had an increasing tendency due to deterioration of the paper raw materials on an annual basis. However, after the application of FFS Product in December 2016, the steam consumption rate has decrease since January 2017. On average, this customer achieved a 6% reduction of steam consumption.

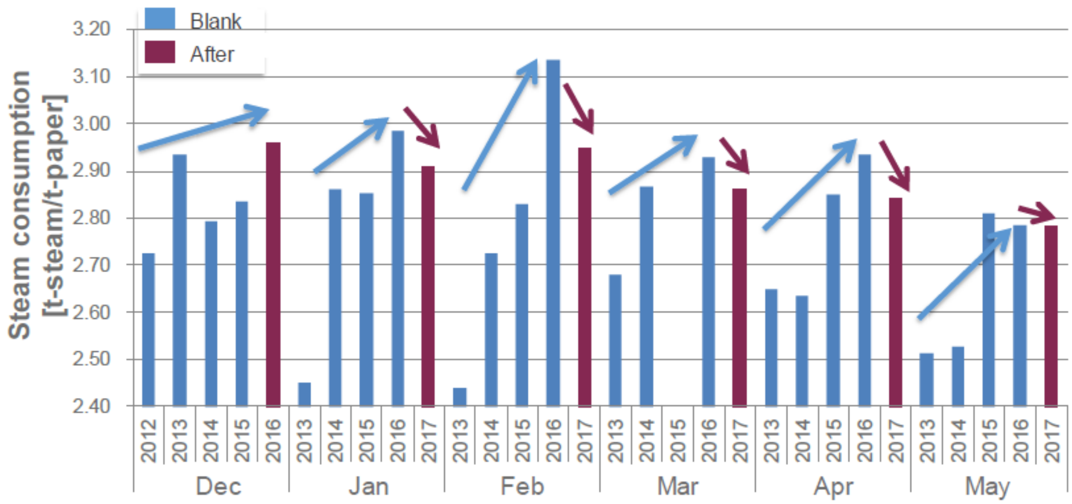

Figure 12 Steam consumption (t)/ production ratio (t)

CONCLUSIONS

The effectiveness Kurita Dropwise Condensation Technology in improving heat transfer efficiency was confirmed and verified through laboratory experiments and field applications.

1. Kurita Dropwise condensation technology demonstrate vastly improved heat transfer efficiency of 30%. This has been accompanied by dosing 20 g/t continuously before the target heat exchanger.

2. Kurita Dropwise Condensation Technology show excellent performance in reducing the steam consumption rate typically by 5 – 10%. Kurita Dropwise at dryers of pulp and paper factories has been successfully applied to over 70 plants globally.

As described above, Kurita has applied Kurita Dropwise Technology to more than 70 plants at dryers of pulp and paper factories since 2017. Typically, 5 – 10% steam consumption reduction is realized in the 15 types of paper machines shown in Figure 10. We are currently verifying this technology in pulp and paper mills, and in various types of heat exchangers across multiple industries as a means to increase heat transfer efficiency.

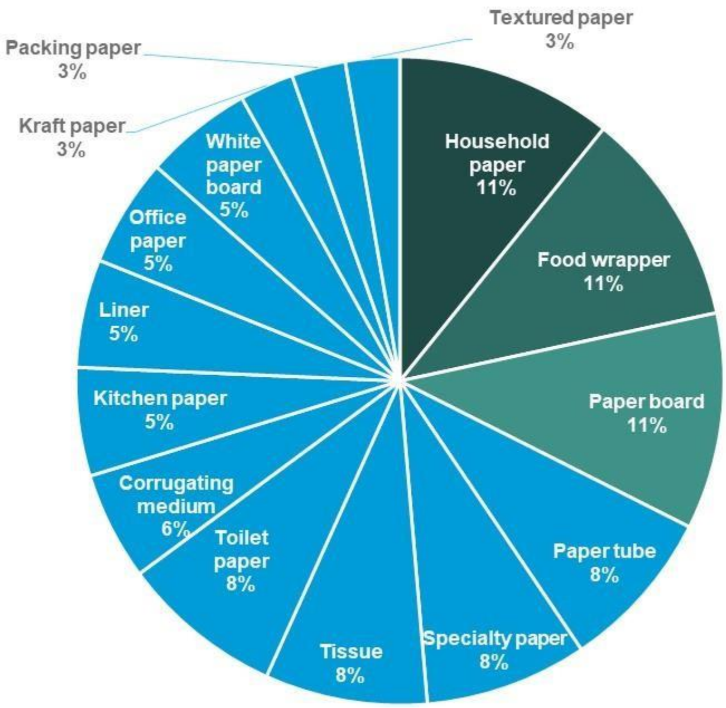

Figure 12. Application distribution by type of drying machine

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