Automated design and optimization of cooling lines for extrusion using chillWARE cooling simulation

Cite as: AIP Conference Proceedings **1779**, 030006 (2016); https://doi.org/10.1063/1.4965476
Published Online: 31 October 2016

Kenny Saul, Gregor Hiesgen, Manuel Moellenbeck, and Chris Rauwendaal

Automated Design And Optimization Of Cooling Lines For Extrusion Using chillWARE Cooling Simulation

Dr. Saul, Kenny[1, a)], Dr. Hiesgen, Gregor[1)], Moellenbeck, Manuel[1)], Dr. Rauwendaal, Chris[2)]

1) *SHS plus GmbH, Erlenstr. 20, 46149 Oberhausen, Germany, saul@shs-plus.de*
2) *Rauwendaal Extrusion Eng., Inc. 10556 Combie Rd PMB 6677 Auburn, California, USA, chris@rauwendaal.com*

[a)] *saul@shs-plus.de*

Abstract. Every production system for extrusion processes consists of a cooling section. The optimal design for the cooling section is not easy to find and influences the investment costs, the operating costs and the product quality significantly. The chillWARE® software system is able to calculate the whole cooling situation for extruded products (e.g. pipes, coextruded pipes, cables, sheets, films, profiles) and to give information about the necessary space, the number of spray cooling sections or the temperature level for the cooling fluid. In a completely new feature, an optimization algorithm was integrated into the software system to propose an optimal design for the complete cooling section using only a few necessary process parameters like the product dimension, the available maximum space for the production plant or the type of the processed polymer. The optimization system can be enabled to reach an optimal distribution of residual stresses within the product wall or (as an example) to realize the minimal operating or investment costs. The whole simulation system is based on the method of finite differences/elements and can be controlled using an intuitive graphical user interface and an automated report function.

INTRODUCTION

Modern extrusion lines feature great flexibility in regard to the realizable product spectrum. Universal screw geometries, modern extrusion die technologies with modular injector concepts as well as automatically adjustable sizing sleeves allow for the production of a wide range of different product geometries on one and the same extrusion line. Obviously, the system has to be designed in a way that "boundary processes" (e.g. maximal throughput) can be achieved with a maximum of production reliability. In reverse, this design strategy means that the production line is only running on partial load for many processes and thus is utterly over dimensioned for standard operations. Partial load of electric components usually leads to a decrease of their efficiency rates and thus to an increase in operating costs as well as environmental pollution.

Even more inefficient than partial load is the operation of plant components which are not needed for the process as well as unnecessary load on ancillary equipment (e.g. cooling water temperature too low).

Due to the fact that every extrusion line was designed for a case of maximum load, in practice situations like this occur on almost every extrusion line. Consequently, there must exist a multitude of processes which run on an over dimensioned production line with low energy efficiency. If no action to optimize the parametrization of the process is taken at this point, its cost effectiveness is also greatly reduced.

Besides this economic aspect, it can be asserted in regard to the cooling of polymer melts that the cooling gradient has a significant impact on the product quality.

Proceedings of the Regional Conference Graz 2015 – Polymer Processing Society PPS
AIP Conf. Proc. 1779, 030006-1–030006-5; doi: 10.1063/1.4965476
Published by AIP Publishing. 978-0-7354-1441-9/$30.00

Plastics are some of the worst heat conductors in existence [1], and this special characteristic can be curse and blessing at the same time. On the one hand they are predestined for applications in which a good thermal insulation is required on the other hand they are quite difficult to process. The heat which is introduced into the material in the melting process has to be withdrawn again in a protracted and time intensive cooling process in order to obtain a geometry-stable product.

While in the melting process (in the extruder) the transformation of mechanical energy into heat (dissipation) can be utilized in addition to electric heating, the cooling process has to rely on the classic mechanisms of heat transport, like thermal conduction, thermal radiation and convection. This is why oftentimes the cooling section limits the maximal production velocity and in many cases also takes up the most space of all of the production equipment.

Because of this high efforts are made to try and shorten the cooling section or, alternatively increase the output that can be achieved with the means available. To reach this goal the temperature of the cooling water is reduced, cooling tanks are flanged together to avoid air sections or additional cooling devices (often based on compressed air) are installed. After such measures are taken and the production line is set up for a little higher output, the results are oftentimes quite sobering when it is discovered that suddenly quality problem emerge which were unheard-of beforehand or the energy costs are unexpectedly high, so that the new process becomes completely uneconomic compared to the standard procedures.

Although the fundamental interrelationship between the degree of the crystallization or the diameter of the resulting spherulites in connection with the cooling gradient are generally well-known and publicized [1, 2], such aspects are rarely considered in the extrusion of pipes, sheets and profiles [3].

The uncontrolled reduction of cooling water temperatures can cause residual stress inside the products which can later lead to geometry problems (e.g. warping, shrinkage, ovality), stability problems (e.g. internal pressure creeping) or problems which occur on further processing of the product (e.g. collapsing of pipe ends). Also, reducing or avoiding air sections, so-called tempering sections worsens these problems. In most cases the material is prevented from dispelling residual stress when running through the cooling section while at the same time the cooling efficiency is not even improved.

Along with the quality problems it can be assumed that a reduction of the cooling water temperature by 1 K causes the energy costs of the chiller unit to rise by approximately 4% [2].

According to experience layout and parametrization of cooling sections in most companies is done following strategies which are established and unquestioned for years and furthermore are even universally applied to the whole product range. Oftentimes, when parametrizing cooling sections no discrimination between different products is made, neither in regard to the materials nor the product dimensions.

AUTOMATIC COOLING SECTION DESIGN USING COMPUTER SIMULATION

These are exactly the points which are addressed by the cooling simulation software chillWARE. The computation system chillWARE 2D is based on the finite differences method and can be utilized to simulate the exact cooling behavior of extruded products like mono- and multi-layered pipes, coatings, cables and solid rods while taking into account how varying cooling water temperatures, air sections, cooling tank technologies or different materials effect the characteristics and operating costs of different production processes.

The module chillWARE 3D on the other hand is based on the finite elements method and is suitable for simulating production processes of extruded sheets, films and profiles.

In addition to the previous functions (as published in [4], [5] and [6]) for optimizing processes and existing production lines, the system now features a completely automated cooling section design function. The software automatically determines the optimal cooling section configuration, based on the individual specifications of a product (e.g. material, geometry and dimensions, material throughput, processing temperature) and suggests an initial layout to the user (initial design). The algorithm considers the product geometry as well as the desired material throughput and the haul-off speed. In addition, while generating the initial design the prices for cooling tanks of different manufacturers are taken into the equation in order to keep the investment costs for a new production line as low as possible. Based on this analytic initial dimensioning, the user can now activate a hybrid optimization algorithm which automatically computes and optimizes the cooling section in an iterative approach. As a result the user receives a completely configured cooling section with all the corresponding cooling diagrams.

The time which is required to complete these calculations depends on the complexity of product and process but usually it only takes between some minutes and a few hours. The accuracy of the results surpass those of the usual design strategies (which rely on estimated rules of thumb, e.g. 0.4 m of cooling length per kW melting power) by several orders of magnitude – especially when the cooling section is designed for products with fast line speeds or high wall thickness or when an additional internal cooling is applied to the process.

Another new feature of the chillWARE simulation system is the automatic Production Plan Analysis (PPA), which offers the unique possibility to automatically examine arbitrarily complex and extensive production plans to avoid the problems described above and increase the economic efficiency. The approach to this is intuitive and simple: The production plan (which is often provided by the equipment manufacturer) as well as the configuration of the cooling section (number and length of the cooling tanks) are entered into the software, afterwards the fully automatic Production Plan Analysis is started.

As part of the automatic optimization of the individual processes, the chillWARE cooling simulation system progressively analyzes the temperatures in the cooling tanks, the activity of the cooling water cycling pumps and the length of the air tempering sections and further cooling section parameters. Resulting from this the software assesses the intensity of residual internal stresses and how the resulting production costs can be reduced or the throughput increased. It also calculates the temperature gradients, as well as additional parameters (e.g. energy costs, quality and productivity).

Every single result is exported to a report file and saved for further use. In addition, the system identifies the processes for which the given cooling section is over dimensioned, which are running at t a low energy efficiency rate or are responsible for low product quality. The software then suggests measures for possible process optimizations, which can subsequently be applied to the production line control system.

To transfer the results to an actual production line three standardized data interfaces are available in addition to the manual data export function. They allow direct import into the recipe management system of an extrusion line. At present, the systems of Hans Weber Maschinenfabrik (from version WPS3 onwards), Krauss Maffei (from version C6 onwards) and SHS plus GmbHs' own system autoCHILL® are supported.

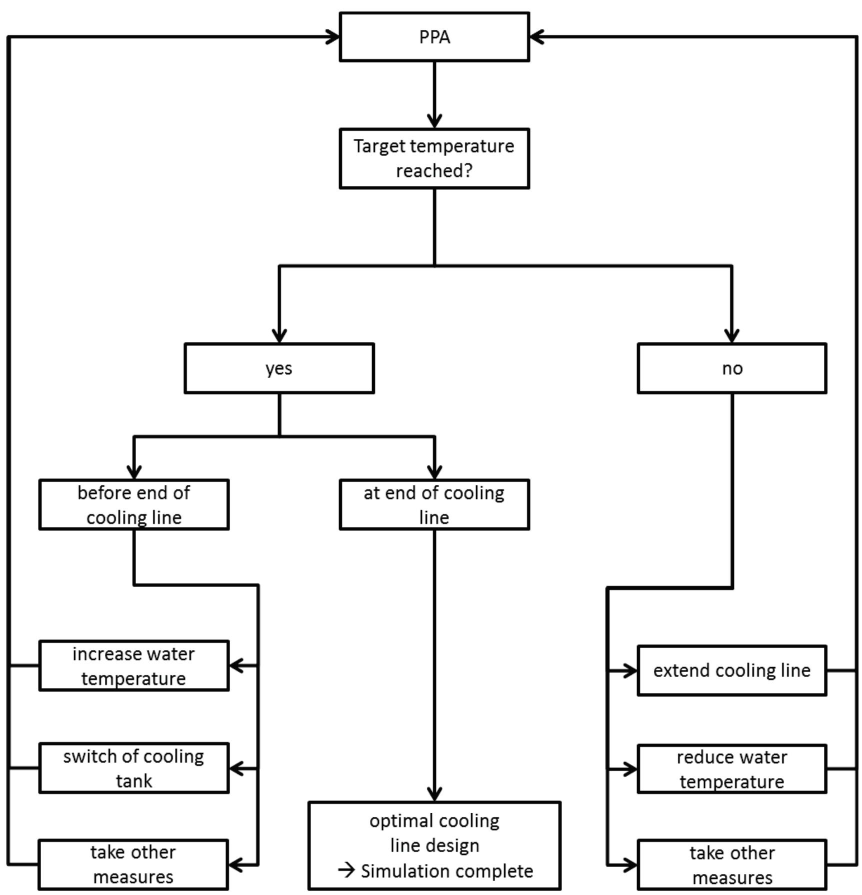

FIGURE 1. Exemplary visualization of a part of the chillWARE optimization procedure

EXPERIMENTAL SETUP AND IMPLEMENTATION

The test is conducted on an extrusion line with five spray cooling tanks, of which the first two are vacuum enabled and flanged together. Every cooling tank is followed by a tempering air section of 1 m length, so that the total length of the cooling section is 49 m plus 11 m of downstream equipment (caterpillar haul-off, saw, package unit, etc.). After the cooling line layout is entered into the simulation system, the production plan, which is available as Excel-file, is imported into the system. The plan consists of forty production processes with different values for mass throughput, pipe diameter, wall thickness and haul-off speed. The parameters for the reference process are shown in table (1).

The simulation is carried out on a personal computer with a 2.9 GHz dual-core CPU and 4 GB of memory and runs in a robust manner without errors and takes 4 hours and 23 minutes to complete. It needs one to five iteration steps for each respective process.

TABLE 1. Reference process parameters

Parameter	Value
Material	Polyethylene, High Density
Cooling water temperature	15…17°C
Ambient temperature	20°C
Mass temperature	210°C
Target temperature	60°C
Boundary conditions for production cost analysis	EER chiller unit = 3.5 EER dry cooler = 35 Energy costs = 0.16 €/kWh Operating hours = 150 h / process

RESULTS

After the simulation is done, an automated report file is generated. Figure 2 shows the number of each individual process on the X-axis and the corresponding residual stress on the Y-axis. The values for the respective reference settings are drawn as dark grey bars and the optimized results as light grey bars. It can be clearly recognized that a reduction of the residual stress is possible for almost every process in the plan when the parametrization of the cooling section is adjusted accordingly. Figure 3 again shows the number of the process on the X-axis. On the left

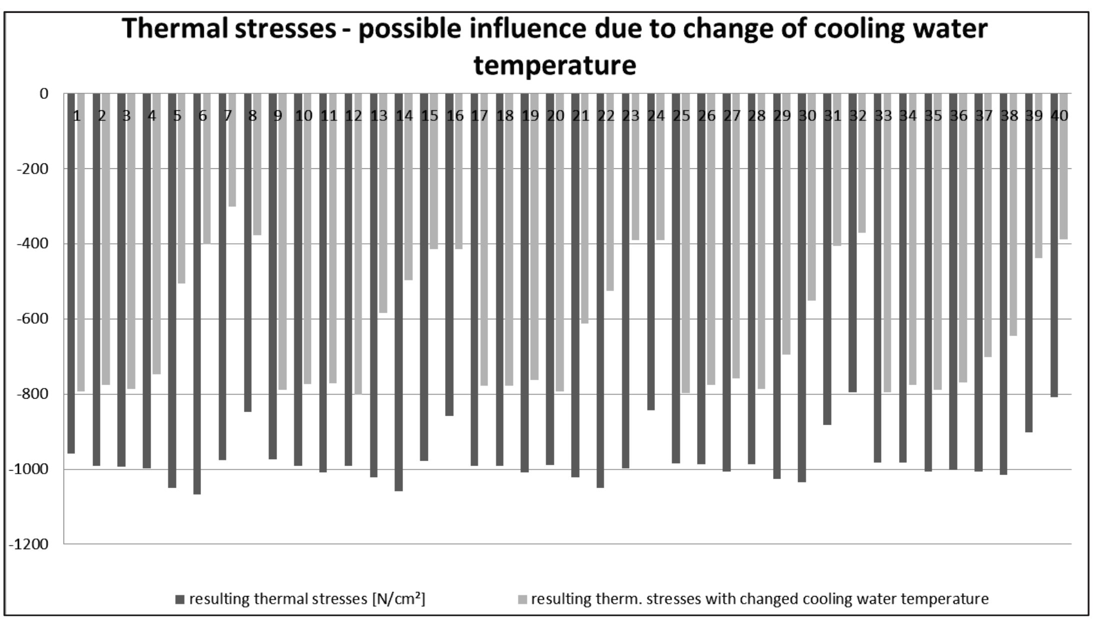

FIGURE 2. Chart of thermal stresses in each process

Y-axis the percentage of the utilized cooling length for the respective process is depicted. The dark grey bars correspond to this value. The right Y-axis depicts the number of cooling tanks that are unnecessary for a given process and can be switched off to conserve energy and reduce residual stresses in the pipe wall. The light grey bars and the number inside them correspond to his value.

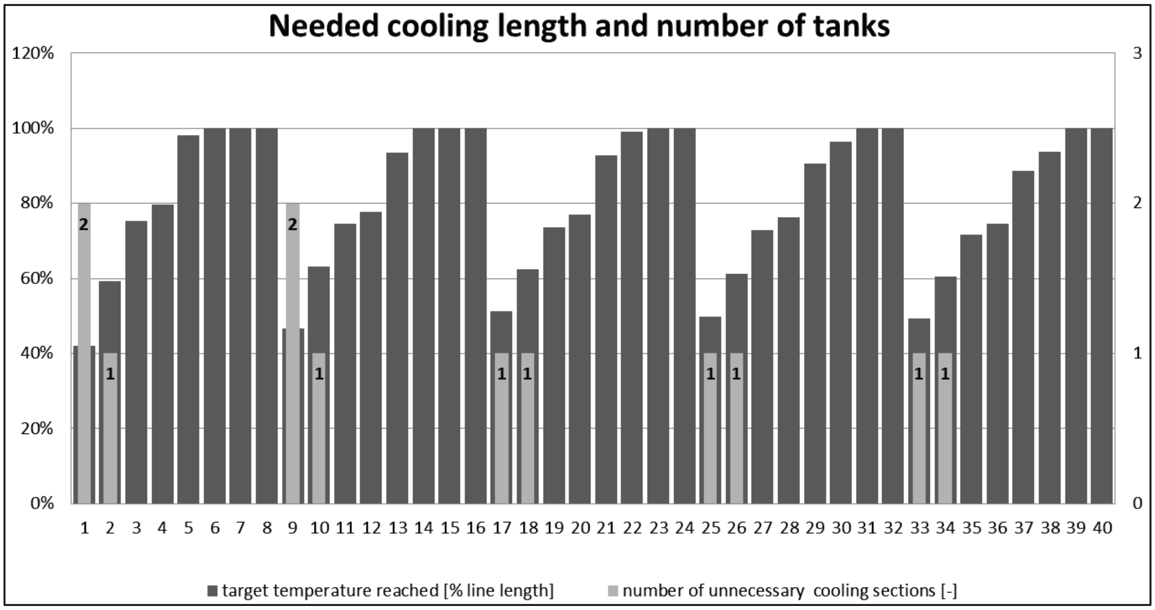

FIGURE 3. Lengths of cooling lines used and unnecessary cooling tanks

CONCLUSION

Extrusion lines are designed for a maximum of production reliability at their nominal operating point; naturally this includes the cooling section. In todays practice a multitude of products with very different material throughput rates is produced on one and the same extrusion line. Because an adaption of the cooling section to the requirements of a specific process is oftentimes omitted, the production runs on sub-optimal parameters. But efficient process control has a great impact on production costs, product quality and line productivity. The Production Plan Analysis feature of the chillWARE cooling simulation system makes it possible to analyze production lines and complete production plans and adjust the different cooling processes in regard to optimal production results.

REFERENCES

1. Menges, Haberstroh, Michaeli: *Werkstoffkunde Kunststoffe*, Carl Hanser Verlag, 2011
2. Osswald, Schmachtenberg, Brinkmann, Baur: *Saechtling Kunststoff Taschenbuch*, Carl Hanser Verlag, 2013
3. Moneke: *Die Kristallisation von verstärkten Thermoplasten während der schnellen Abkühlung und unter Druck*, Dissertation, Darmstadt, Technische Universität Darmstadt, 2001
4. Hiesgen, Saul, Spitz, Weiss: *Pipe cooling simulation for energy savings and enhanced product quality*, Proceedings of the Polymer Processing Society 28th Annual Meeting ~ PPS-28 ~ December 11-15, 2012, Pattaya (Thailand)
5. Hiesgen, Saul, Spitz, Weiss, Wortberg*: Application of the finite difference method for the cooling process simulation of multi-layer pipes and cables*, Proceedings of the Polymer Processing Society 29th Annual Meeting ~ PPS-29 ~ July 15-19, 2013, Nuremberg (Germany)
6. Weiss, Hiesgen, Saul, Spitz*: Cooling simulation for the prediction of quality properties and production costs of semi-finished extruded products like pipes*, Plastics Engineering, June 2014 & SPE ANTEC 2014, 29th of April, Las Vegas, Nevada, USA