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Requirements and Opportunities for Sustainable Process Optimization

Analysis, Execution & Profitability

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Filename:	Requirements and opportunities for sustainable process optimization.docx
Number of pages:	11

1 Table of contents

1 Table of contents 1
2 About this lecture 2
3 Process problems to be solved 2
4 Possibilities of process analysis and optimization 3
5 Requirements for sustainable process analysis 3
5.1 Product data 4
5.2 Observations of the operators 4
5.3 Polymer data 4
5.3.1 Rheological properties 4
5.3.2 Density 4
5.3.3 Thermal properties 5
5.3.4 Raw material properties 5
5.4 Fixed System Parameters 5

5.4.1 Geometries of the polymer leading components 5
5.4.2 Drive and heating/cooling power data, sensor technology 5
5.5 Process data 6
5.5.1 Values from the line visualization 6
5.5.2 Values from the control units 8
6 Possibilities of data acquisition 11
6.1 Use of an existing interface of the control 11
6.2 OPC UA interface 11

2 About this lecture

What does sustainable process optimization mean? It means nothing other than finding and solving the actual cause of your process problem and not just improving the obvious symptoms. Granted: Fighting the symptoms is easier, often faster, usually more expensive - but it just does not lead to long-term success, but to the next necessary symptom fight.

My presentation essentially describes which requirements are necessary for sustainable process optimization and which options are generally available at present. This applies not only to pipe extrusion lines but is ultimately applicable to all extrusion processes, because the process steps and requirements for economical production are essentially the same everywhere. And the physics of polymers, their mechanical, rheological and thermal behavior also apply equally to all plastics processing operations.

3 Process problems to be solved

By far the most common difficulties in production are process instabilities, which manifest themselves in deviating quality of the end product and are responsible for a high reject rate and frequent production interruptions.

In many cases, consistent product quality can be achieved in the first approach by reducing the line speed, but this no longer makes the process economical.

The flexibilization of production with short product runtimes and changing operating resources demanded by many managers also presents process engineers with new tasks. What are the control parameters when transferring a process to another extrusion line with deviating components? Or when switching to a different raw material or additive? In these cases, the absolute values from the original plant can only provide indications, but only specific variables can be compared directly with each other. Specific variables can be calculated: From the process data in combination with geometry and performance data.

Particularly challenging for the process engineer are processes that run very well for hours and sometimes days. And then suddenly, disturbances occur for a short time, which on the one hand can lead to the interruption of the process or after which the process stabilizes again on the other hand. The latter disturbances are quite dangerous, because they are often not noticed at the plant. In the worst case, the modification of the end product resulting from the disturbance only becomes apparent during use due to the failure of the product.

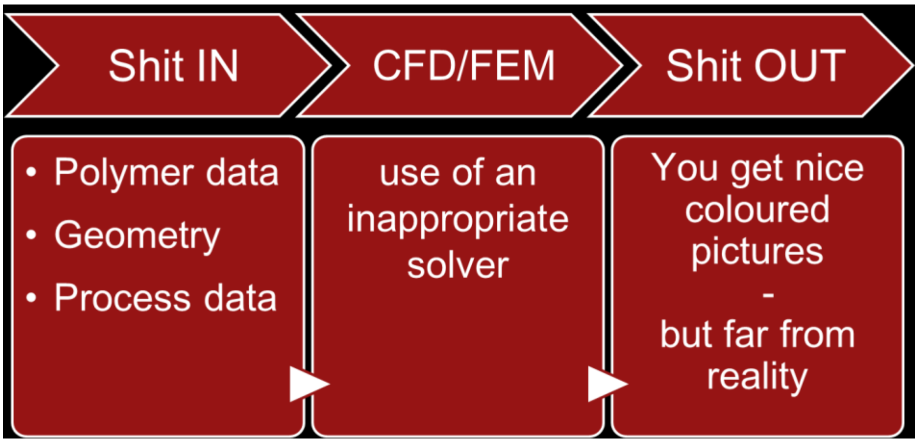
In such a case, it is practically impossible to analyze the problem afterwards. On most modern lines, it is documented when the product was extruded on which line. But what actually happened on the line during this period?

So what is required to be able to identify the cause(s) of such problems even at a later stage by a comprehensive process analysis?

4 Possibilities of process analysis and optimization

In addition to conventional statistical evaluations and analytical calculations, process simulation is also particularly useful for the analysis. Here, the numerical flow simulation of extrusion dies and extruder screws, but also the simulation of cooling are particularly worth mentioning.

Today we have gained very interesting insights into the possibilities of simulation methods. CFD simulation provides insight into the process, independent of production and without consuming resources. With experience in the evaluation of the results we can find possible causes of the problem. However, the accuracy of the simulation always depends on how the boundary conditions are set. There is a simple law for simulation that applies to all simulation software: Shit in - Shit out.



If the used polymer data do not correspond to those of the processed material, the simulation cannot represent the real process. In addition, of course, you should note that solvers for turbulent air flows are completely unsuitable for studying laminar polymer flows. You will always get colorful nice pictures. The accuracy of the results of a simulation depends mainly on the used solver and the correspondence of the entered boundary conditions with the actual conditions.

5 Requirements for sustainable process analysis

So we need data - lots of data. And what is very important: All these data require a synchronized time stamp. Only by referring to the same point in time is it possible to determine, taking into account the average residence times in the individual components. Do not exclude any process step in advance from the analysis. For example, could a new polymer batch be the cause of the problem? Was there perhaps a malfunction at the dryer? Was a change of setting made on the line and not documented? When did the mold pressure or screw speed start to creep? Or perhaps the temperature or flow rate of the cooling water.

There are so many parameters.

Or is it in the end the geometry of the extruder screw or the die? This would mean high costs for changes or new purchases and an unavoidable longer downtime of the line.

You must always be aware that your conclusions from the analysis can cause very high costs for the sustainable solution of the problem. So go into the analysis with an open mind. At the end, the management will ask the legitimate question whether the result and the resulting consequences are certain with a very high probability.

5.1 Product data

It is only necessary to mention for the sake of completeness that the calculated product data, i.e. the specification of the extrudate including the cross-section drawing and the calculated or targeted line speed, must be available.

5.2 Observations of the operators

It is essential to include the observations of the plant operators in the analysis. They may provide an initial indication of the cause of the problem. However, you must not take these indications as fact without further analysis of the data and without your own observations and possibly draw a wrong conclusion about the problem-causing component from them. When operators get stuck with their symptom-fighting efforts, they often point to problems with the extruder screw or die in general. All melt-carrying areas of the system are hidden from the observer and therefore provide endless room for speculation and the most diverse theories.

5.3 Polymer data

Collect the polymer data from the manufacturer, ideally already when purchasing the material. However, the usual data sheet with the properties of the plastic is far from sufficient - and unfortunately it confirms itself again and again: It is really difficult to get the polymer data required for a process analysis. If your polymer supplier cannot or is not willing to provide the data, you have to contract a laboratory to measure the various properties.

But which polymer data do you need beyond the usual ones?

5.3.1 Rheological properties

In the optimum case, you obtain data from a 2-channel high-pressure capillary rheometer

- Shear viscosity vs. shear rate function at at least 3 temperatures (CARREAU-WLF).
- Extensional viscosity vs. elongation rate function at at least 3 temperatures (COGSWELL).

5.3.2 Density

- Bulk density, kg/m^3 for the investigation of material storage and conveying up to the extruder screw
- Solid density at room temperature
- Melt density at processing temperature for the investigation of all flow processes inside the extruder and the die and behind the die

5.3.3 Thermal properties

The thermal properties at room temperature are usually included in the general data sheets, the data at processing temperature usually have to be requested.

Required data includes:

- Specific heat capacity J/(kg K) for cooling and energy balances
- Thermal conductivity W/(m K) is important for all extrudate cooling studies
- Specific enthalpy J/kg
- Melting temperature
- Freezing temperature

5.3.4 Raw material properties

Required data includes:

- Pourability, s is especially important for the processing of powders (e.g. PVC dry blends) and in this case a quality criterion that must be checked regularly in the plant
- Grain size
- Grain size distribution

5.4 Fixed System Parameters

It doesn't matter what analysis you have to do - detailed knowledge of the line components is required. However, the layout drawings included in the plant documentation are not sufficient for this, they only provide an overview.

5.4.1 Geometries of the polymer leading components

In addition to the layout drawings of your line/components, the polymer-side dimensions of all polymer-carrying components are required. Since an exact measurement of e.g. extruder screws and extrusion dies after commissioning of the line is difficult and above all requires a longer shutdown of the line, you should already request these documents from the manufacturer when purchasing the line or component.

5.4.2 Drive and heating/cooling power data, sensor technology

Information on installed power (drives, heating, cooling) should be available, as well as gear ratios and the types of sensors for temperature, pressure, flow rate, etc. It is also generally recommended to check all speeds mechanically. If an incorrect gear ratio is stored in the plant software - I have experienced all of this - the results of the simulation will always differ from reality.

Also the pressure sensors have to be calibrated regularly to make sure that they show the actual values.

In principle, an extrusion line cannot have too many sensors, but they must also function reliably or be properly calibrated.

5.5 Process data

We know that we have to perform further calculations with the process data for a sustainable problem solution. How do we get this data as effectively as possible? Just writing it off from the visualization? Probably not! This method takes too much time and the data are incomplete!

5.5.1 Values from the line visualization

Modern visualizations show the most important parameters of the entire line, but the data are usually only available as a limited CSV export. You can imagine the effort if you can transfer only 8 of, for example, 1000 parameters at a time with an export in CSV. The visualization is not available for plant operation during your export work. This leads to the fact that usually only the "suspicious" parameters are exported and the actual cause is not captured at all during this export.

Since this export is always a retrospective, you can only fall back on recordings and observations that were also documented with the synchronized point in time. As you continue to summarize and analyze the data, you may realize that you still need other parameters. At this point, however, the desired data may no longer be available. The data are usually overwritten again after a certain period of time, since memory space is limited. Your analysis will thus be incomplete forever.

Another disadvantage of this method is that the exported data has very high temporal resolution, so the amount of data is extremely large, although only the pressure in the extruder or, for example, the signal from a proximity sensor can change in a very short time. All other parameters are subject to longer-term fluctuations. In practice, it has been shown that an interval of 5 seconds is completely sufficient for a detailed analysis.

In addition, the values from the visualization are scaled, with temperatures usually rounded to whole numbers, i.e. 268°C instead of 267.5°C. This rougher resolution can lead to misinterpretations by itself. For example, the melt quality may be more inhomogeneous with a seemingly constant displayed value of 268°C than if the displayed value constantly fluctuates between 267 and 268°C. How uniform the melt temperature actually is can only be determined with a higher resolution of the value. This is because a fluctuation between 267.4 and 267.5°C represents a much better temperature uniformity (and thus homogeneity) than a fluctuation between 267.5 and 268.4°C which, however, makes a constant and thus very homogeneous melt temperature appear.

Abb. 1 Melt temperature with 1 digit

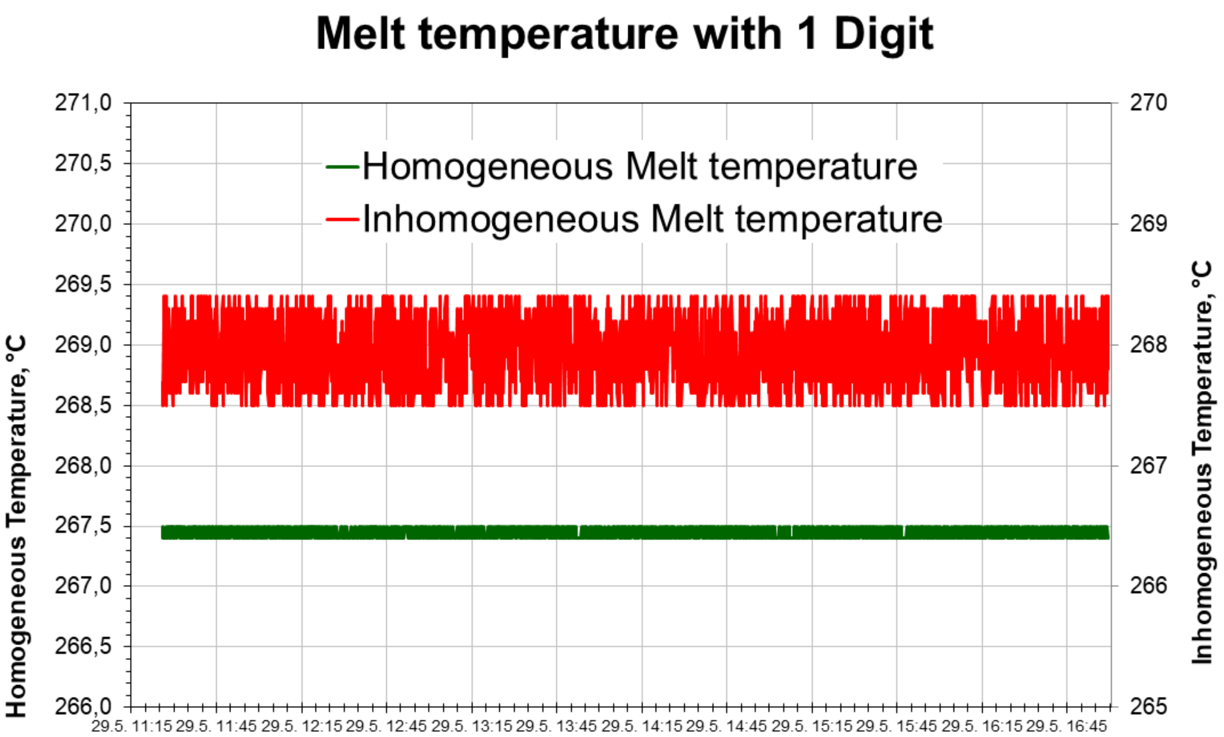
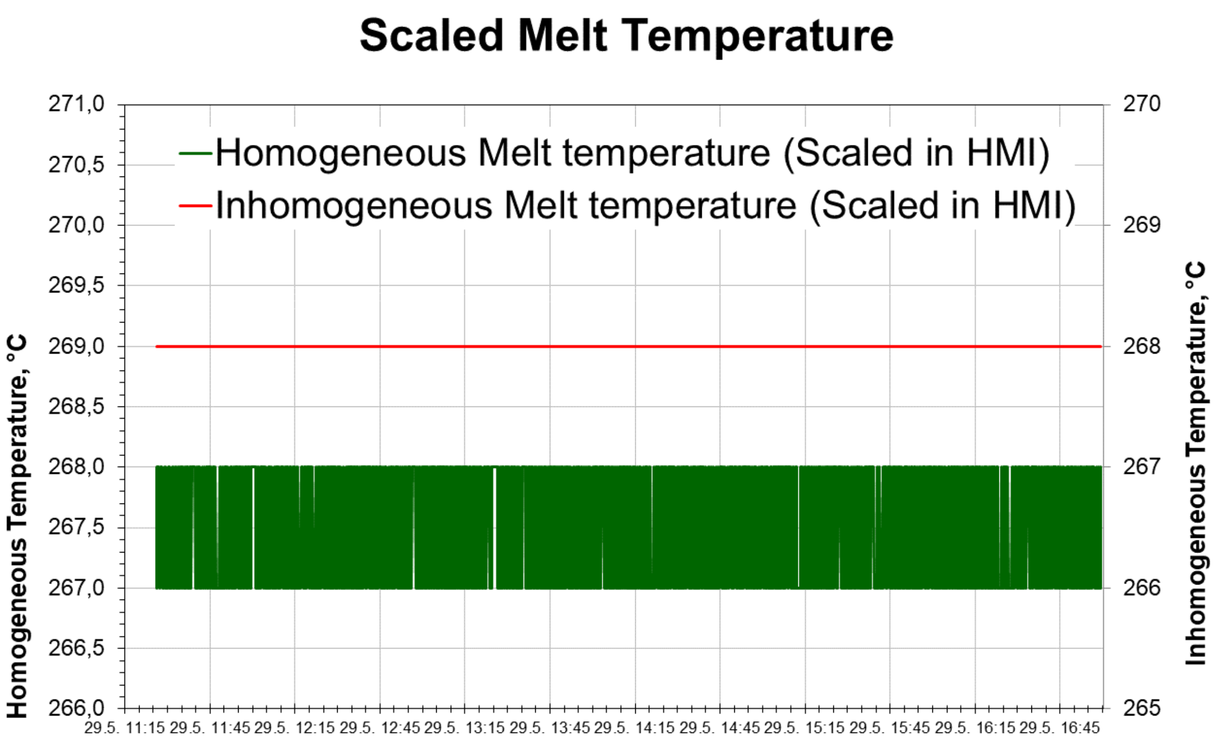


Abb. 2 Scaled melt temperature (rounded to integer)



As the melt temperature can only be measured during production with the sensor technology available in the line, this parameter is of great importance. It should be noted that the measured value is strongly dependent on the type of sensor and the installation situation. In absolute terms, therefore, the value cannot reflect the actual temperature - but this does not affect the constancy!

The data from the visualization are therefore insufficient for a comprehensive analysis of the process. The analysis with simultaneous observation of the process is not possible.

Therefore, visualization should be used for what it was designed for:

For the operation and control of the plant.

5.5.2 Values from the control units

The best source for all data in the highest possible resolution and completeness is always the control unit of a line, in case of decentralized control the control units of all components. In principle, all process data are available here as variables. But how can this data be made usable?

Most often, the analyses are done by the process engineers in MS Excel®. Here, tables are kept, which are filled either with the data from manual records or CSV imports (or a combination of both).

Now the process engineer can start with his actual task and perform certain calculations with the data. For statistical procedures for the correlation of certain parameters - as described before - there is usually not enough data available.

The easiest way is to read the control data directly online into MS Excel® , to update them continuously and to calculate with these data. The updating of the variables is controlled via the interface between the extrusion line and MS Excel® , an interval of 1000 ms is completely sufficient for our purposes and does not overload the control.

With Visual Basic for Applications (VBA) it is also possible to record data directly in MS Excel®. However, this is not possible in real time, the shortest interval is 1 second. This short interval is a problem for the computer if many calculations with the transferred data are running at the same time. However, an interval of 5 seconds is unproblematic and also completely sufficient. This means that you will receive a new data set of all variables of your controls and the calculation results every 5..10 seconds.

It is also possible to enter remarks that will be assigned to the dataset stored at that moment. Because, of course, all other fixed parameters of the line (geometries, drives, etc.) and the polymer data are also stored in the file.

This finally makes it possible to apply statistical methods and find possible correlations. The application is operated online and offline in the same way.

All data you need for a sustainable process analysis are summarized in 1 file.

Diagrams make it possible to follow the process over the time online and to observe the process live at the same time. If you make changes to the setting, the parameters and the behavior of the process can be observed at the same time.

Furthermore, it is possible to have a report created at any point in time. We can also summarize a longer period in a report and make statistical evaluations for all parameters. From this, a recipe for this product on that line can then be created very quickly.

MS Excel® offers the process engineer a variety of analytical methods and also has the great advantage that it is usually available anyway and its operation is familiar.

The HMI in the MS Excel®-Application works very similar to the real Visualization of the line. Actual values are green, setpoint values are yellow. It is possible to change the setpoints of the line, but not recommended. You may allow this feature for special tasks, for example to upload a recipe to the line. For normal use it is recommended to allow only the reading of the data. The actuating variables of the controllers are shown in purple color, the calculated values are shown in blue.

By clicking on the values a predefined diagram opens as new window. So you are able to compare several diagrams at the same time. Because it is MS Excel®, you can of course adapt the diagrams individually to your wishes.

Abb. 3 The HMI as central user interface in MS Excel®

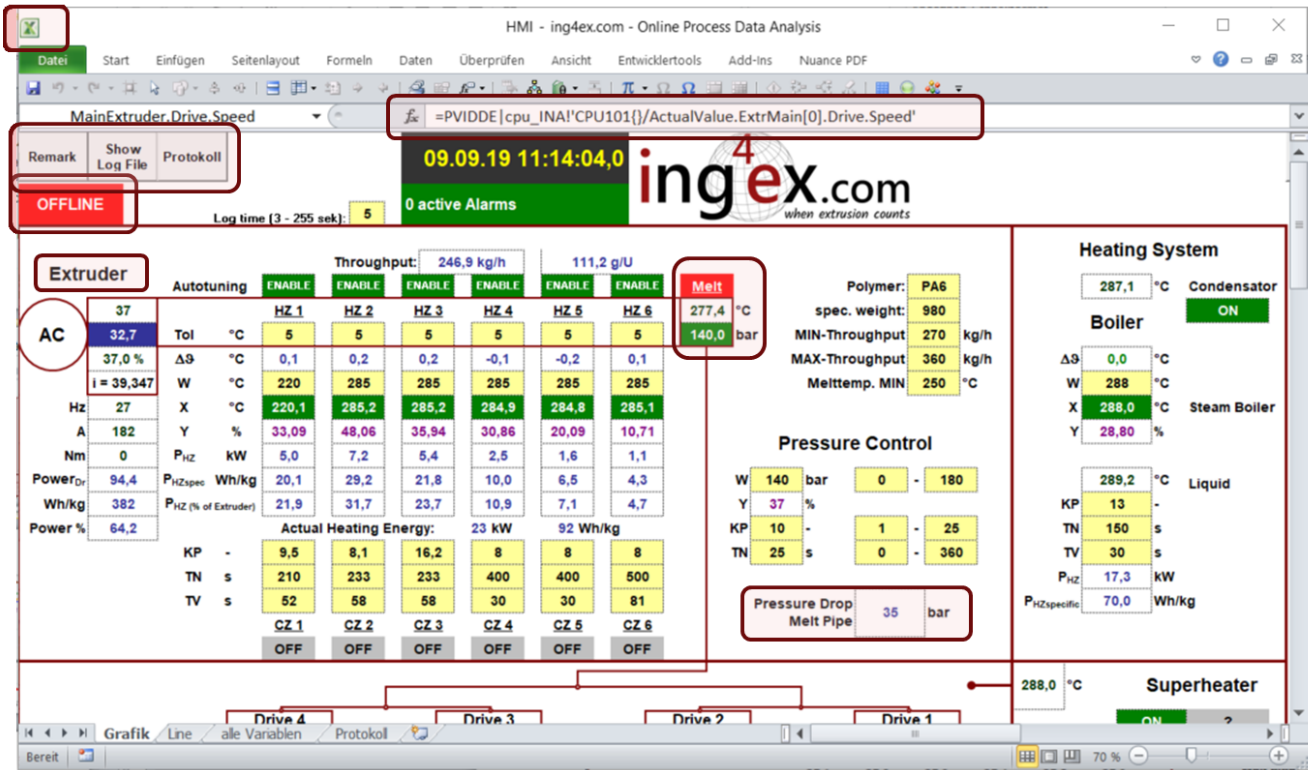


Abb. 4 A typical diagram

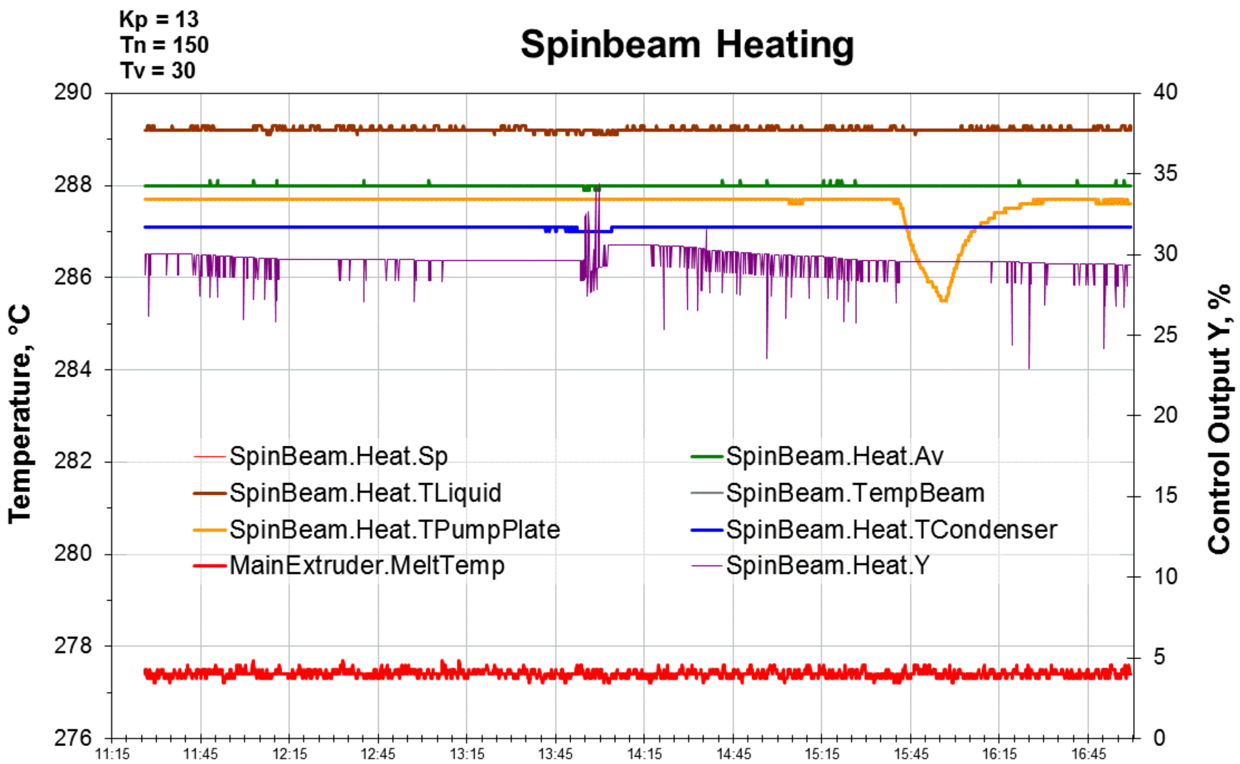


Abb. 5 The average report gives you a quick overview about the stability of the line.

20210412-1125.xlsm - ing4ex.com - Online Process Data Analysis

Datei Start Einfügen Seitenlayout Formeln Daten Überprüfen Ansicht Entwicklertools Add-Ins Nuance PDF

12.04.21 11:26:07,0 **Report - Average Values**

Customer: **Customer** Trial: TEST

Log File: **20210412-1125.xlsm** Machine: E1.130-26D

Average Data from: Mo, 12.04.21 11:26:07 to: Mo, 12.04.21 16:59:22 - 2000 Values

Line Throughput, kg/h: + 247 (+ 0,0 / - 0,0)

Melt Temperature Extruder 1, °C: 277,4 (+ 0,3 / - 0,2) **Melt Pressure Extruder 1, bar:** 139,9 (+ 0,1 / - 0,9)

Extruder 1 Screw: Original Mixer: Original

Heating	Setpoint, °C		Actual Value, °C		Δ (T), °C		Y Heat, %		P heat, kW			% of Heating Power Main Extruder
	Average	Range	Average	deviation of average	Average	Range	Average	Range	Average	Range	Specific	
HZ 1	220,0	+ 0 + 0	**220,0**	+ 0,4 % - 0,1 %	- 0,0	+ 0,9 - 0,3	33,9	51 0	5,09	7,7 0,0	20,6	21,2 %
HZ 2	285,0	+ 0 + 0	**285,0**	+ 0,1 % - 0,1 %	- 0,0	+ 0,4 - 0,3	51,6	59 43	7,74	8,9 6,5	31,3	32,2 %
HZ 3	285,0	+ 0 + 0	**285,0**	+ 0,3 % - 0,2 %	- 0,0	+ 0,8 - 0,6	40,7	63 13	6,11	9,4 1,9	24,8	25,4 %
HZ 4	285,0	+ 0 + 0	**285,0**	+ 0,1 % - 0,1 %	+ 0,0	+ 0,4 - 0,4	30,7	37 25	2,45	2,9 2,0	9,9	10,2 %
HZ 5	285,0	+ 0 + 0	**285,0**	+ 0,1 % - 0,1 %	+ 0,0	+ 0,4 - 0,4	15,8	22 10	1,26	1,7 0,8	5,1	5,2 %
HZ 6	285,0	+ 0 + 0	**285,0**	+ 0,1 % - 0,0 %	+ 0,0	+ 0,2 - 0,1	13,9	18 9	1,39	1,8 0,9	5,6	5,8 %

Extruder 1 Drive Power: 147,0 kW Current: 284,0 A

Drive Values	Actual Value			Y Drive, %		Specific Values
	Average	deviation of average	Range	Average	Range	
Screw Speed, min^{-1}	**36,7**	+ 6,3 % - 4,6 %	39,0 35,0	+ 37,40	39 36	112 g/round
Frequency, s^{-1}	**28,0**	+ 5,1 % - 4,2 %	29,5 26,9			
Current, A	**183,1**	+ 1,6 % - 1,5 %	186,1 180,4			384 Wh/kg

Pressure	Setpoint, bar		Actual Value, bar			
	Average	Range	Average	deviation of average	Range	
Extruder outlet	140,0	+ 0 + 0	**139,9**	+ 0,1 % - 0,6 %	140,0 139,0	
in front of Pump	-	- -	**106,0**	+ 14,2 % - 1,9 %	121,0 104,0	
Drop Extruder to Pump	-	- -	**33,9**	+ 6,2 % - 44,0 %	36,0 19,0	
Die	-	- -	**199,4**	+ 3,8 % - 0,7 %	207,0 198,0	

MainExtruder SpinBeam Offline Protokoll AverageValues

Bereit 100 %

If certain limits are exceeded or undershot, the cells are automatically colored accordingly. Of course, you can define these limits yourself.

Abb. 6 The report for 1 dataset – create it online or later offline for a certain point of time

Online Process Data Analysis
Page 1 / 3

REPORT

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17.04.2021 00:36:27 **Demo** 0

Machine: 686.0

Extruder 1

Heating	*AV, °C*	SP, °C	Δ (T), K	Y Heat	P (Heat)	% of Heating	Cooling	Y Cool	P(Cool)	Kp	Tn	Tv
HZ 1	*220,1*	220	+ 0,1 K	33,09 %	5,0 kW	21,9 %	OFF	0,0 %	0,0 kW	9,5	210	52
HZ 2	*285,2*	285	+ 0,2 K	48,06 %	7,2 kW	31,7 %	OFF	0,0 %	0,0 kW	8,1	233	58
HZ 3	*285,2*	285	+ 0,2 K	35,94 %	5,4 kW	23,7 %	OFF	0,0 %	0,0 kW	16,2	233	58
HZ 4	*284,9*	285	- 0,1 K	30,86 %	2,5 kW	10,9 %	OFF	0,0 %	0,0 kW	8,0	400	30
HZ 5	*284,8*	285	- 0,2 K	20,09 %	1,6 kW	7,1 %	OFF	0,0 %	0,0 kW	8,0	400	30
HZ 6	*285,1*	285	+ 0,1 K	10,71 %	1,1 kW	4,7 %	OFF	0,0 %	0,0 kW	8,0	500	81
Pressure:	*140 bar*	140 bar	0 bar	37 %						10,0	25	-

Melt Temperature, AV: 277,4 °C

Drive	Screw Speed	Frequency	Current	Load	P (Motor)	spec. Power	Torque	eta
actual:	32,7 rpm	27,22 Hz	182,3 A	64,2 %	94,4 kW	382,2 Wh/kg	0,0 Nm	

Spinbeam

Heating	*AV, °C*	SP, °C	Δ (T), K	Y Heat	P (Heat)			Kp	Tn	Tv
Vapour:	*288,0 °C*	288 °C	+ 0,0 K	28,80 %	17,3 kW			13,0	150	30
Liquid:	*289,2 °C*		**+ 1,2 K**			Pressure in front of Pump:	105 bar			
Spinpack:	*287,6 °C*		- 0,4 K			Pressure Drop Extruder to Pump:	35,0 bar			

6 Possibilities of data acquisition

So we have seen that the transfer and evaluation of the control data in MS Excel® offers the greatest benefit. Various options are available as an interface in between.

6.1 Use of an existing interface of the control

Numerous manufacturers of control systems already offer integrated interfaces to MS Excel® , which are not chargeable in all cases. In older plants, the connection is made via a serial interface, in modern plants via TCP/IP. In the rarest cases, however, all components of an extrusion line, from material logistics to unwinding or the deposit of an extrudate, are equipped with controls from the same manufacturer or integrated into a central line control system.

6.2 OPC UA interface

For such cases, the data transfer via an OPC server is the best option, which transfers the data of all control units bundled to MS Excel®. OPC stands for Open Platform Communications and UA for "Unified Architecture" and is an internationally standardized communication interface that is defined independently of manufacturers and platforms. OPC UA is one of the leading communication protocols for Industry 4.0.

An OPC server handles the communication between the OPC clients. These are the control units of the line and our MS Excel® file.