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FUTURE TECHNOLOGIES IN THE POLYMERIC SHEET EXTRUSION INDUSTRY

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Trabalho apresentado ao Curso de Graduação em Engenharia de Materiais da Universidade Federal de Santa Catarina como parte dos requisitos para a obtenção do título de Engenheiro de Materiais.

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Este Trabalho de Graduação foi julgado adequado para a obtenção do título de Engenheiro de Materiais e aprovado em sua forma final pela Comissão examinadora e pelo Curso de Graduação em Engenharia de Materiais da Universidade Federal de Santa Catarina.

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Abstract

This work aims to explore new technologies and changes in the production of polymeric sheet through extrusion for the next 10 to 20 years. Several interviews with specialists on the subject were developed in order to understand their visions for the future of the polymeric extrusion of sheets. The information gather on the interviews were divided in to different themes, similar and complementing answer were join together. These themes represent an area of improvement discussed during the interviews; three were the number of themes. They are reduction on energy consumption, automation and machine customization. Reduction on energy consumption shows solutions on reducing the energy used in the process and increase of efficiency to decrease the amount of energy entering the process. Automation presents steps towards increases in productivity and flexibility through out the implementation of monitoring systems and production quality controls. The steps were divided in three, being the first already being implemented therefore a more concrete view, the second and third present more uncertainty. The last theme is machine customization, there it is discussed accessories, modular parts that could be used during the production of specific product, in order to make it viable to produce smaller and more customized batches.

Key words: Polymeric sheets extrusion, future technologies, polymeric extrusion

Resumo

O trabalho busca explorar possíveis novas tecnologias e mudanças na produção de chapas poliméricas por extrusão para os próximos 10 a 20 anos. Diversas entrevistas foram realizadas com profissionais e especialista na área, buscando conhecer suas visões para o futuro na produção de chapas poliméricas por extrusão. As informações da entrevistas foram divididas por temas e agrupadas, respostas semelhantes e complementares foram juntadas. Três foram os temas discutidos durante as entrevistas sobre melhorias na área. Redução do consumo energético, automação e customização das máquinas. A redução do consumo energético apresenta soluções de como reutilizar parte da energia do processo. Também, soluções de melhoria em eficiência afim de diminuir a entrada de energia no processo. Automação apresenta os passos para se atingir maior produtividade e flexibilidade através da implementação de sistemas de monitoramento e controle da produção. Os passos foram divididos em três, o primeiro mais concreto e que já está sendo implementado; e conforme vai para o segundo e terceiro passos a incerteza aumenta. O último tema do trabalho é customização de máquinas, lá é discutido possíveis acessórios, peças modulares que possam ser implementados para produções especificas com o intuito de viabilizar a produção de bateladas menores com maior customização.

Palavras chaves: Extrusão de chapas poliméricas, tecnologias futuras, extrusão polimérica

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1. Introduction

Plastic is a fundamental material in today's society. Its ability to have several colors, easily shaped and a vast properties range, make them a convenient material for a huge range of applications. The plastic industry uses screw extruders as the principal process to melt and shape the material in to products. For long time extruder is the method used to process polymer because of its ability to provide shearing and heat. The screw introduces shearing that mix and dispersed the polymer providing a homogeneous melt and generating most of the heat. When extra heat is necessary the extruder can add more energy through heating elements. Extruders have proven to be a very effective method to process plastics. The technology of screw extrusion during the last years showed changes regarding machinery size, shape and extruder concepts (SAKAI, 2013). The history has show that the machinery suffered a constant increase in size. Mainly to improve production output. Also the number of screws for different applications can vary. To reduce maintenance different alloys were developed. Most of the advances were to improve output, reduce maintenance or to address special material issues. However, the concept of using a screw to melt the material still the same. It has proven to be a robust and efficient method for plastic process and it is the fundamental piece of machinery at polymeric sheet extrusion. The question is: What should be the new technologies and features in the polymeric sheet extrusion?

This work aims to explore technologies for the future of the extrusion line in the manufacturing of sheets. The focus is to present features that will be implemented at screw extrusion in the next 10 to 20 years. More specific goals for this work are to list new technologies in the area and list future trends. The work collected ideas during interviews with experts in the area. The ideas were developed in concepts and briefly described during the interviews. Those experts shared their knowledge and opinion on what technologies and features should be implemented in the future. The work cataloged and agglomerated the ideas in clusters. Each cluster contains several ideas about the same area of improvement. The final results serve as a guideline to engineers, managers, researches and anyone how work in the polymer extrusion industry, special in the plastic sheet extrusion sector. The conclusion of this work helps to visualize those changes and explain why they are important. Some new features are a trend across the whole plastic extrusion industry; others are more specific to the sheet polymer sector.

The work starts by giving a briefly review of the current state of screw extrusion technology. Explain some of the important parts and systems along the line. Gives an overview of the features presented today. Later it explains how the data was collected to answers the research question. Then the interviews process is detailed. The structure and how were interviewed is described. Next is presented the results of this work. Here the reader can find all the ideas collected during the interviews in an organized format. The new features are grouped in cluster, where similar ideas are presented together. So the reader can easily get the ideas of the topic he is interest the most. Not necessary having to read the whole written work. The discussion is presented after the result. There the author explores the ideas and gives opinions based on trends observed in the industry and the interviews realized. Also here some possible limitations of this work at explored and discussed. At the conclusion an overview of the work is given along with suggestion of future works.

2. Theory

Theory part aims to highlight the main areas of work regarding of the literature point of view. Also situate the reader on the currently development in each area.

2.1 Polymer Extrusion

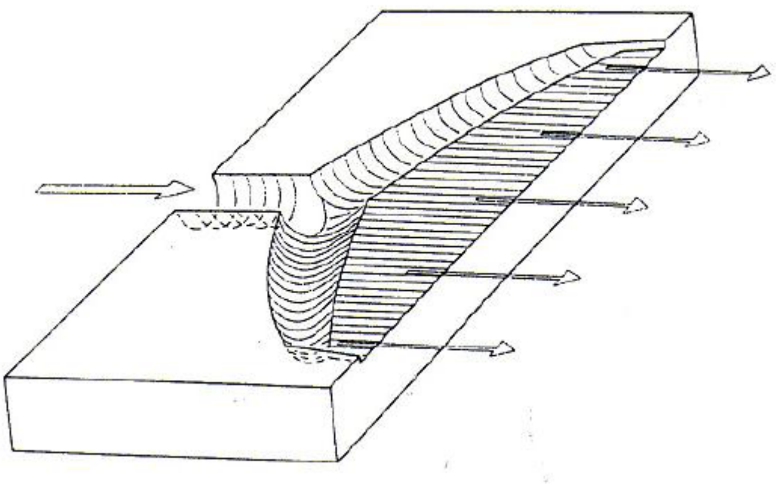
Polymers are broadly used in several different applications. The main reason is because of the vast range of different types existing of it and properties like low density and corrosion resistance. Another advantage of polymer over metal and ceramic is the processability. Compared to other class of material like metals and ceramics, polymers present a better processability making them economically competitive (CHUNG, 2019). The way from raw polymeric materials to finish products is what defines polymer processing (TADMOR; GOGOS, 2006). Polymeric materials are processed mostly by extrusion methods. Extrusion is characterized by a material being forced through a hole, also known as die, thus acquiring the hole's shape. After the material leaves the die it has a constant cross section with continuous length (LEVY; CARLEY, 1989). The plastic extrusion occurs in steps, first the material is plasticized, also common know as melted. Then it is forced thought an orifice where it acquires shape. Without a discussion, extruders are the most used and fundamental equipment in the polymer processing industry (RAUWENDAAL, 2014). Extruders exist in different size a configuration. The most used are the single and double screw extrusion. The double screw extrusion can have screws turning co-rotating or counter-rotating. Depending on the application, the extruder type and size are selected. From the extrusion process it is possible to product pipes, windows profiles, cables, technical profiles and sheets.

2.1.1 Polymeric Sheet Extrusion

Polymeric sheets is one area inside the plastic industry. They are used at civil construction in floor and walls, in the transport sector to produce interior parts for cars, planes and trains, in industrial application like to build tanks for chemical storage. The sheets can be produced by extrusion, press or calendaring process. Sheets are produced from pressing method when isotropic properties are required and calendaring is common used in PVC (Polyvinylchlorid) because of it low thermal stability. However, extrusion is the most used one because of its considerable output advantages compared with the others alternatives.

The sheet extrusion process has some special parts that shape the material, let it cool and cut. The production starts with an extruder that is feed granules or powder. Depending on the resin the extruder can have one or two screws, and not some common there are also extruder with planetary screw. Twin screw extruders are commonly used for PVC production, because of its high dispersing and mixing power. For polyolefin's single screw extruder are common used because it can build easily pressure to operate the die. Planetary can be used to process material where a high degassing efficiency is required, because it offers a high specific area. The combination of two different configurations can be implemented, therefore enjoying the benefits of both extruders. For example, a twin-screw used to properly mix the raw materials followed to a single screw that quickly build pressure to operate the die. After the material is well mixed and melted at the barrel, it goes through the die. For sheet production a coathanger die is used. The coathanger with split dies and flexible lips allows production of sheets in the range of 0.3 to 30 mm (OSSWALD; BAUR; RUDOLPH, 2019). It has two channels that spread the melt along its width with a constant thickness, giving a flat shape to the material. Just before the melt leaves the die it goes through the die lips. The flexible lips provide a fine adjustment to the melt flow behavior. Image 1 shows a schematic of a coathanger die. They can regulate the amount of material that leaves the die in a specific zone, so tuning the thickness profile.

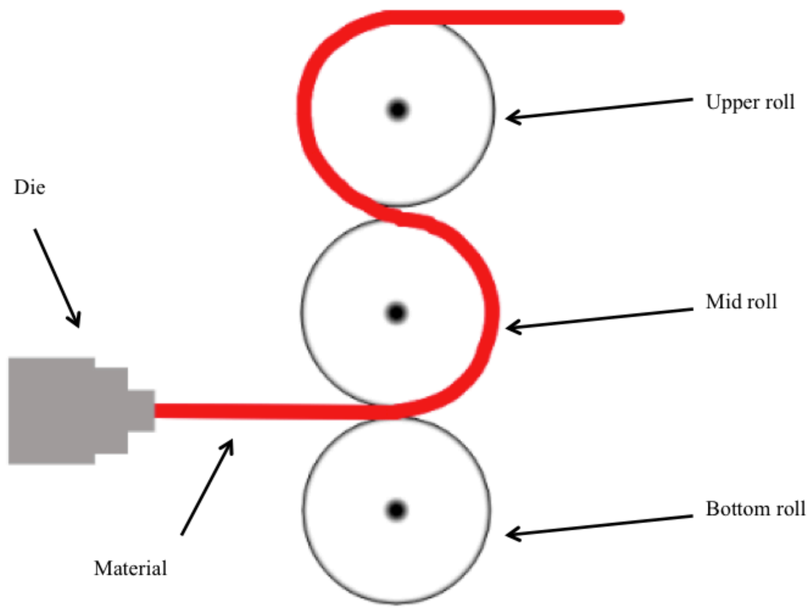
Image 1 - Schematic of a coathanger die



Source: VLACHNOPOULOS (2008)

The next step is the rolls stack or roll calender. The rolls stack can have several configurations regarding number off rolls and size, usually they are composed of three rolls. The material passes through the first and second roll, then makes a 180 degree turn and passes upper in the second and third. Finally makes another turn to leave the calenders, from the top surface of the upper roll. Image 2 shows a draw from the side of the three roll and the die. There it is possible to see how the material passes through the rolls after it leaves the die.

Image 2: Shows a draw from the side of the material passing through the rolls.



Source: Author

When passing between the rolls the material is squeezed. So the distance gap between the rolls is an important factor responsible to give the final adjustment of the sheet thickness. The rolls also can be heat or cool the material. Depending on the material and thickness energy is applied or removed at the calenders. Most common is used heated/cooled oil inside the rolls to adjust the surface temperatur of the sheet. Once the material leaves the rolls calenders it already has the final desired thickness. A set of rollers conveyor are used to cool the material. The equipment transport the material in a long set on rolls, similar to a mat. There the material has time to decrease its temperature. The sheets slowly losses energy to the air, usually no force cooling is applied. Thick sheet may require slower cooling or even a tempering treatment. Because its surface cools as the core still warm generating internal stress. These internal stresses can decrease the mechanical properties of the sheet because they act just like an external load (OSSWALD; BAUR; RUDOLPH, 2019). Since the surface was cooled when the core was still warm, the core when is cooled introduces a compression force, because it wants to contract but it is fixed. Heaters are used during the conveyor to anneal the surface and relieve those tensions. Along the rollers conveyor as the material cools down, knifes cut off the board of the material. The edges do not have the same thickness as the core, so they are trimmed off and grinded to be reprocessed. These knifes are responsible to the final width for the sheet. Adjusting their position the final product width can be altered. A saw or guillotine is used to make the transversal cut that gives the final dimension to the sheet, its length. Since the production is continuous the saw has to move diagonally at the production speed to provide a straight transversal cut. Finally the sheets are piled up with the use of a hanger. The hanger grabs the sheets at the line and place them on top of a pallet. Then the pellets with the sheet are transported to the logistic department where they are shipped to customers.

2.2 Automation

The manufacturing of goods is fundamental to provide a strong economy. These industries provide jobs and generate growth. Therefore several countries are investing in technologies to increase manufacturing efficiency: Germany introduced in 2011 the term Industry 4.0 as a national strategy to automation (DEMETRIUS KLITOU, 2017), where the whole supplier chain would be connected, and the information running between the manufacturing industries and consumers. Angela Merkel, German Chancellor, mentioned "We must (…) deal quickly with the fusion of the online world and the world of industrial production. In Germany, we cal it Industry 4.0" (DEMETRIUS, 2017, pg3) in her quote shows Germany's interesting in the fourth industrial revolution. Japan throughout the fourth industrial revolution wants to reach the "Society 5.0", which is the connection of physical and cyber spaces (G20 HAMBURG, 2017). United States of America launched a partnership program for advanced manufacturing where it plans to stronger industry and research institutes to develop and implement new technologies (THE WHITE HOUSE, 2013). Brazil has an automation schedule in place under the name "Agenda brasileira para Industria 4.0" where it plans to use the advantages of technologies like Internet of Things (IoT), artificial intelligence (AI) and cyber physical systems to increase the overall industry competitiveness (BRASIL, 2020). The benefits of the fourth industrial revolution promises to change industries, people's lifestyle and business (NAGANO, 2018). Automation of manufactory promises to increase efficiency and production capability, increasing the competiveness; allowing high wage manufacturing places to compete with low-cost countries (FROHM et al., 2006). "These technologies (talking about automation and AI), and that human-machine interaction, will bring numerous benefits in the form of higher productivity…" (MCKINSEY, 2018). The technologies of automation can reduce the human work load (BRETON; BOSSÉ, 2003), also improve working conditions, because they can eliminated boring and repetitive tasks. More important, harms and unhealthy work activities can be realized machines (PHAM Q.C., 2018). Since the benefits of increase the automation are vast, companies, research institutes and university are working on the topic. To reach Industry 4.0 several new technologies are being developed. The main technologies are Big Data, Internet of Things, robotics, Artificial Intelligence, Cyber Physical Systems and Enterprise Integration (LU, 2017). When implemented in combined these technologies will be able to interconnect the whole supply chain of manufactory product and consumers (RÜßMANN et al., 2015). Currently many industry leaders have the necessity to specialize themselves and continually learn these new technologies in order to being able to guide and quickly adapt in order to distinguish themselves as successful industry leaders (SCHWAB, 2017).

Nevertheless, the literature also shows challenges regarding automation. There are several works talking about the risks and disadvantages of automation for workers. Also, there is not a direct effect of automation use and benefits results (BAINBRIDGE, 1982). Graetz (2015) work shows that among low and middle skilled workers the implementation of robots on the work environment can lead to a reduction in salary; the same work tells no significant reduction in working hours. In today’s economy the benefits of automation probably will not be shared among social classes, and the owner of the technology will enjoy it most of its benefits. (PHAM Q.C., 2018). Jeremy Rifkin (1995) in his book "The End of Work" talks that automation will generate great benefits for the stockholder but those benefits will not be seen for the average employee. Therefore automation will increase the wage gap between the top managers and the workforce. He mention that this re-engineering revolution is capable of harm a very important group in the society, the middle class. The workload does not have its reduction even among the workforce (SARTER; WOODS; BILLINGS, 1997). In some cases, when not properly implemented, it can increase workload and slow expertise development (AMALDI; SMOKER, 2012). Automation can increase the work environment complexity, requiring training for the workers and demanding new work skills. It can require special skill to make maintenance at the systems and fixing problems as they appear (DELOITTE, 2020). Over automation can cause workers to rely too much on the technology and do not perform at their potential (MARCUS HATTEN, 2020).

2.3 Energy Savings

Humans will have a great challenge in the twenty-first century, and that is climate change (DESSLER; PARSON, 2019). Today most countries have a mix of power generation through renewable and non renewable sources, being electricity generation the responsible for the largest amount of fossil-fuel emissions (SCHIERMEIER et al., 2008), thus even worsening the climate situation. For example; Germany has about half of its electricity generated through renewable sources (FRAUNHOFER, 2020). The necessity to decrease the amount of greenhouses gases in the atmosphere, shift the use of energy from fossil fuel to renewable sources. It also implicates in industries adopting higher efficiency technologies and process. Thus according to the European Union (EU) 2030 climate & energy framework, the goal are to reach 40 percent cut in greenhouse gas emissions, 32 percent EU energy generation from renewable sources and 32.5 percent improvement in energy efficiency by the year 2030. The energy efficient usage goal is under the Energy Efficiency Directive 2012/27/EU. Another motive to decrease energy consumption is to maintain and gain competitiveness. In the U.S. plastic manufacturing industries are investing in solutions to increase energy efficient in order to increase the overall competitiveness. As the price of electricity increases, it turns to be a preoccupation for the sector and energy efficiency solutions become more attractive (THE SOCIETY OF THE PLASTIC INDUSTRY, 2003). This means that the industries sector and consumers will each have to adjust their activities to reach environmental target; and manufacturing plastic industries must implement energy solutions to keep competitive in the market. Aiming to increase competitiveness by less energy consumption and losses, machine manufactories are constant developing more efficient extruder. Today the driven system present the most influence in the process (ROSATO, 1998). Therefore should be the area most focused on increasing efficiency.

3. Methodology

The topic of this work is "Future Technologies in the Polymeric Sheet Extrusion Industry". It is a project developed by the student Vitor Augusto Buehring in order to achieve his bachelor degree. The project was developed at the company SIMONA AG in the city of Kirn, Germany. During the period of 15.10.2019 until 29.02.2020 and under the supervisor of Nils Harries.

The goal of this project is to collect ideas, suggestions, and predictions about what should be the changes in the production process of polymeric sheets. Since the work grade ideas and concepts the method chosen was experts interview, a qualitative research. The main reason is that a qualitative approach allows for a deeper understanding of the subject studied and also allow a greater degree of freedom on the analyses of the topic throughout discussion. The process to answer the research question was the collect of data from employees at the company SIMONA and outside key companies on the extrusion technology field. The information was collected in the format of expert interviews.

3.1 The Interviews

The interview type chosen was the expert interview where experts in the extruder technologies were interviewed. Experts are those how have great amount of knowledge in the area, usually through years of working and studying the subject. The goal from the interviews was to have the greater amount of ideas and insides from the experts as possible. Therefore the interviews were all with open-end question allowing for long answers and the most amounts of information sources. A format similar to brainstorm where discussing and argumentation was used during the interviews. The interviewed were, when relevant, fed with ideas from others interviews. Thus stimulating creative and allowing them to give feedbacks and complementing others ideas already shared. When possible the interviews were realized in person. The conversation lasted usually 45-60 minutes. A coffee was often shared between the participants with the goal to make the conversation as comfortable and informal as possible. The approach of calling a conversation instead of interview also had the aim to decrease formality. Thus creating an ambient more comfortable for sharing ideas and where there are no wrong answers. However some talks with outside partners were realized over the phone, because of the distance.

An email was sent prior to the interview to set a time and place. With the email a brief resume of the project was attached. There the expert could find information about the project and also could have a better idea of what to expect in the interview. The email usually was sent a few days before, so the interviewed would have time to think about the topic and generate ideas.

Creativity and imagination, together with experience in the area are required for answering in a coherent way the questions and generate good ideas inside the topic. The format of the interviews allow for great creativity and imagination. However, sometimes too much imagination can steer the conversation to topics beyond this work. When that happens the interview becomes too abstract and outside of the scope. Aiming to correct this problem a guideline was created. The next section explains better what is was this guideline, also called catalog of question. The guideline duty was to keep the conversation inside the work's theme. It was the interviewer responsibility to observe and lightly guide the interview. The guideline helps keep the conversation inside the desired scope. It was made in a way that still leaves the conversation very open, allowing for creativity and imagination, and at the same time maintaining the topic of this work as the goal.

Some interviewed had the opposite problem. The expert did not know ideas at the beginning of the interview. They had trouble identifying areas to improve on the extruder lines. When that happened another feature was used. The interviewer mentioned some general trends seen in the industry with the goal to stimulate ideas. General trends like reduce of energy consumption, reduce of scrap, increase of output, quality, automation solutions, etc. When some general trends were mentioned the expert had time and a few examples of possible areas of improvement. Thus promoting him to list ideas in some of the trends cited. Also allowing the interviewed to think of something he had not thought before. Thereby enriching the information at the conversation and also the overall result.

3.1.1. Catalog of questions

As mentioned before the interviews are performed at a semi-structured way, in a conversation format allowing the maximum of creativity, imagination and long answers about the topic. The result is a deeper sharing of the technology by experts in the area. Only a guide lined was used to keep the conversation inside the desired scope. The questions were not all the same for all the interviewed. A set of general questions was made based on the main topic of this work (energy saving, automation and customization), those can be seen in the table 1 below. At the same time customized questions were made to allow the person to share ideas inside him/her area of expertise. Outside companies and institutes had a different set of questions during their interviews. Also to optimize the information obtained according with their area of work and development.

Table 1: It shows some general questions used as a guideline during the interviews.

What trends do you see for improve output?
Do you see the length of the line changing in the next years?
Do you see Length/Diameter ratio increasing even more for the next years?
What trends do you see to decrease energy consumption?
What do you think about pre heating the granules?
Which technologies do you see for decrease the energy consumption?
What trends do you see for decreasing the scrap material produced?
What trends do you to increase machine automation?
How do you see the steps of reaching industry 4.0 in the plastic industry?
How do you see machine's automation control when a company uses machines from different suppliers that each uses a different control system and software?
Do you see one big player in the market making a standard controlling technology system or do you see each company developing its own controlling technology?
Virtual Assistance Systems for Extrusion: Does it through data analysis suggest process parameters change to the machine operator?
Do you see any new technology being implemented different than the ones we discussed?

3.1.2. Experts Interviewed

A variety of persons with different expertise were interviewed. Experts with several years of experience in the industry and researchers from institutes and universities that study extrusion and compounding were interviewed. Also manager that work on selecting and implementing new technologies in the industry. The experts were select for their experience in the plastic extrusion industry. They were senior researcher in institutes and universities, senior engineers working with development in the sector and manager. The interviews can be divided in experts from SIMONA and outside key partners companies. At SIMONA the department of process development, research and development, management and maintenance made part of the interviews. The outside partners can be again divided in different areas of expertise. They can be sliced in three categories: Universities and Institutes, companies that supply the extruders machines and suppliers of custom solutions for plastic industry.

Universities and Institutes were selected to participate of the work because they usually are working on technologies that will be implemented in the industry in the next 10 to 20 years. These institutions are already thinking and working with technologies for the future. So they have a lot of relevant knowledge about the future technologies.

Extruders suppliers are companies that provide complete or partial solutions for the polymers process. Some provide the whole extrusion line. Those companies have a good overview of the completely process and knowledge in selecting the right parts in the extruder line. They sell extrusion line machinery, give training for employees and recommend partners to work with. Others extruder machinery suppliers are companies that manufacture parts for the extruder line. They are specialized in a specific equipment of the extruder. Thus they have a deep knowledge in a part of the machinery. Usually their whole research and development is focused in that area. So they have great amount of knowledge in a part of the extruder.

Lastly another type of experts were interviewed. They work for companies specialized in providing custom solutions for the plastic industry. Most of these companies provide software systems, quality control systems and others automation solutions. Their product often consist of systems were sensor are used. The systems are focused on improving the production quality and reducing scrap.

3.2. Coding and Grouping the Data

During the interview the topics discussed were written down with a brief explanation. Then later the ideas were further developed and detailed in a document. Once all the ideas were properly written down the document was send back to the expert. To goal was to achieve a two way communication and making sure the meaning of the ideas were described according with his/her intention. Once the document receives a positive feedback from the expert, it was concluded. The next step is to code and group similar ideas.

The ideas from all the interviews were a grouped in clusters. Total there were three clusters of future technologies for the extruders: energy, automation and machinery customization. All the ideas from the interview could be related with one of them. The data from the interviews were careful clustered in order to minimize the correlations between them. So when discussing a technology inside a cluster, that topic could be further discussed without being related to others ideas. The agglomeration of ideas were tried to be achieved as close to MECE (mutually exclusive and collectively exhaustive) principle as possible; in a way where the ideas are presented without overlapping. Therefore each idea could be individually explained and discussed, with the minimum amount of connection between them. Thus, allowing each technology to be individually presented without overlapping with a similar or related technology

4. Results

Each cluster present topics, ideas and technologies that were discussed during the expert interviews. They are also organized in order to be clear of understanding and mainly to distinct different topic from each other. Therefore, presenting the results from this work as close as possible to a MECE (mutual exclusive and collectively exhaustive) principal; allowing the discussion of one topic without connecting and concerning about others parts of the work. This allows the reader to easily check one technology or part without having to read about another previous section.

4.1 Decrease Energy Consumption

The increase in energy usage efficiency was a trend pointed out by experts. Increasing the efficiency at the industries is part of Germany National Action Plan on Energy Efficiency (2014). It is important because currently mix grade of electricity production is one of the sources of green house gases in the atmosphere. Adding to that the energy consumption has a direct influence on the cost. So even that the solution to decrease electricity usage requires investments, on the long term the investments are paid back. The company becomes more competitive, once the production cost is reduced.

To process polymers granulates in to sheet energy is needed. Because the material needs to be melted to later be shaped. However the efficiency in which the energy is used to melt and the number of times the material is heat up and cooled have a big influence on the total consumption. Every step that requires melting the plastic and cooling it down uses energy that cannot be fully recovered. So reducing the number of steps where heat is applied, therefore going for powder to final or semi final product, is important. Another factor is the equipment used to process the material. More efficient machineries can take electricity from the grid, melt the polymer and shaped it, in a more efficient process. Another idea was to recover energy from the production process and reuse it. Most of the experts solutions were on one of the three areas mentioned above. The ideas are shown below.

4.1.1 Higher efficiency electrical engine

The simplest way to decrease energy consumption is to substitute the currently engine to a more efficient one. Nowadays in the market engines with efficiency class IEC 4, regulated by the international standard IEC 60034-30, have efficiency up to 96% according with the standart. It was point out that it is a relative simple and fast way the decrease energy consumption.

4.1.2 Pre Heat of the Material

The experts point out energy recovery as one solution to reduce energy consumption. The idea is take thermal energy from parts that need to be cooled down to pre heat the material entering the extruder. "Pre heating the material up to 80^{o} C can decrease screw input energy by 10 to 20%", compounder researcher at Das Kunststoff Zentrum. When the material is pre heated before enters the extruder the screw need to input considerable less energy to the process. This is do because when pre heated the material come in to the extruder softer than at normal ambient temperature, specially at countries like Germany where in the winter the granules are feed to the extruder at around 278^{o} K (5^{o} C) or even lower temperature. However if an electric heater is used to pre heat the material there is no actual reduction on consumption. To be able to achieve energy saves, the energy must come from areas in the extrusion process where there is in excess, places that usually are cooled. Under it is presented a list of the places of possible energy source to pre heat the granules. Those places at the extruder line may have energy in excess and can be sources of thermal energy than can be used to pre heat the material entering the extruder.

Barrel: The barrel of an extruder can be water, oil or air cooled. The cooling works by circulating one fluid at lower temperature around the barrel. Therefore taking energy from the barrel as the fluid increase in temperature. Then the fluid passes to a temperature controller equipment where it is cooled down and then goes back to the barrel. A simple system of passing the warm fluid through a heater exchange and transferring some of its energy to pre heat the granules could allow the material to enter the extruder at higher temperature and provide overall energy savings.

Stack Rollers: The rolls deck are cooled down using oil or water similar to the extruder barrel. The same system of reusing the energy from the fluid to pre heat the material can be implemented at the rolls deck.

Roller Conveyor: The material after extruder in to a sheet format it is cooled. The cooling process usually occurs naturally, the material as goes through the roller conveyor it losses energy through heat to the air. So the material is at a lower temperature for the cutting process. All the energy lost while going over the roller conveyor could be used to pre heat the feeding section of the extruder. Capturing this energy can be more difficult than the others methods above, however by closing the whole roller conveyor section a current of air can be created. The air flow from the bottom, cold region, to the top where it is warmer. This air current can then be used to heat the material before the extruder. Something to be careful is that this air can contain small amounts of waxes that evaporate form the material at processing temperature. When this air get in contact with cool pallets can happen the waxes condense and agglomerate at the feeding section.

Electric Engine: The electric drives are cooled down using water or air, depending on the model. The water after going through the engine increases in temperature because the drives generate losses during its operation. This excess energy needs to be removed in order to the proper function of the motor. The warm water could heat the material in a similar way as the methods discussed above. So the some of the heat generated by the engine would be reused in the process.

4.1.3 Direct Drive

A direct drive is an electric engine that produces enough torque that eliminates the use of a gearbox. Today the torque to rotate the screw comes from an electric engine, goes through belts or gears to the gearbox. At the gear box the torque is increased and the rotation speed decreased. When transmitting the torque from the engine to the gearbox losses always occur. They can be reduced when proper use and maintenance of the gear or transmission belts, but they always occur. Similar losses happen at the gearbox as the torque is multiplied and transmitted to the screw. When attaching the electric motor direct to the screw all those losses are eliminated. A high torque direct drive is necessary to be able to generate enough torque to direct drive the screw. The direct drive eliminates the energy losses at the gearbox; also eliminate the gearbox itself. The investment can be justified by reducing the consumption and investment savings by not having a gearbox.

4.1.4 Heat and Friction Optimization

There are two sources of energy in put during the extrusion process. Heat energy from the heating element and shear through the screw. Those elements are placed at the barrel and when applied they convert electric energy in to heat therefore heating the material. Today most of them are resistor however there are induction heater. Induction heaters are more fast and efficient than the resistors ones. The second energy input is the motor that power the screw. Actually is the engine that powers the screw, but the screw through friction heats up the material as processed. It is responsible for about 90% of the energy introduced at the process. The measurement of the energy introduced in the process from both sources can help to optimize energy consumption by allowing just the necessary energy be introduced through the heater. Allowing the process to run mostly with energy introduced from the screw and just the necessary being add by the heaters. Therefore decreasing overall energy waste.

4.1.5 Decrease the Number of Steps Process

In the plastic processing industry the material stars as powder and is transformed in to a product. The number of step necessary to reach the final geometry can change according with material type, machines availability and amount additives inside. At each process step the material is heat up and cooled down. The energy required to heat up is dissipated and cannot be recovered. So once the number of steps can be reduced, the amount of energy waste during the process also decrease. Therefore, reducing the overall energy used in the process.

It is common at the plastic processing industry to compound the different powders before extruding the semi-finished or finished product. The compounder companies buy the plastic resin from chemical companies and mix this resin with additives, pigments and fillers. The mix occurs in a compounder extruder. The materials are melted then cut in small granules. To be able to properly disperse the additives in the polymer matrix usually a twin-screw extruder is used for compounding. The twin-screw high shear characteristics are responsible to the homogeneous mix. The next step would be to extrude the granules in to a semi finished or finished product. The processing normally occurs in a single screw extruder, because it can easily build up the required pressure necessary to pass the material in the die.

As mentioned each one of the steps mentioned above heat for later cool down the material. Providing energy that cannot be recovered, at least not fully recovered. Once the powder material can be processed in to the semi or finished product, energy can be saved. This can be achieved in some cases with combinations of different extruders. For example the combination of a twin-screw extruder to disperse the mix and later to a single screw extruder that quickly provide the necessary pressure for the die.

4.2. Automation

Automation was divided in three parts. The parts are thought in a chronological order, each essential and as a step to reach full automation. The first part is more structured and concrete; here the ideas, systems and how should everything work together is detailed and precise. As is goes forward the degree of certainty decrease and the steps becomes more cloudy, with more general characteristics and not so detailed and precise. Then the final step is more an ultimate goal, a vision further in the future. The steps to reach full automation were based on the expert interviews and are specially thought for the polymeric sheet. Different than others conclusion of this work, the automation part of this work were tailor thought and developed for the process of manufacturing polymeric sheets by extrusion, specially the first part that is more structured and detailed. All the solutions and parts mentioned are regarding the extrusion line of polymeric sheets.

4.2.1 Automation Part One

Automation part one started by showing a list of all the functions that need to be automated. The functions are features that need to be altered every time one production order finish and the next start. These functions change machine configuration with the purpose to address the new characteristics of the next production. They also are adjusted during production in order to keep the product inside the desired tolerances. The functions need be able to be adjusted at distance by workers, without have to go at the machine and manually alter to the desired configuration. Ten was the number of functions mentioned by experts that need to be operated at distance in order to control the production at distance. Once the functions were established it was possible to select which machine parts and measuring systems need to be implemented or changed in order to be able to operate the ten functions at distance. Machine parts like hand wheels and leaver, that have be muscle driven by workers, must be substituted by automatic systems electric driven, pneumatic or hydraulic. Therefore they can be actioned at distance as well. The measuring systems are responsible to guide the machine supervisor. They measure and display the production and product parameters. Therefore the measuring systems allow the worker to know what should be altered at the extrusion line. All the ten functions desired to be automated are shown in table 2. There it is possible to see the functions at the left column; in the middle column it is displayed the measuring systems necessary for each specific function and on the right column are the machine parts that need to be automated to execute the changes in process parameters. Annex A, at the end of this work, it is possible to read in more detail the meaning and goal of each function.

Table 2: Shows each function desired to automate; also the measuring systems and machine parts necessary to automate the functions.

Functions	Measuring Systems	Machine Parts
Autom. Recepy Setting	Color Measurement	Dosage Unit
Autom. Die Adjustment	Thickness Measurement	Die lips Die T/R bar
Autom. Thickness Adjustment	Thickness Measurement Rolls Gap Measurment	Rolls Gap Size
Autom. Bank Adjust	Bank Measurement	Die lips Stack Rolls (rotation speed)
Autom. Flatness Adjust	Temperature Measurement Flatness Measurement	Temperature Pressure Rolls Stack Rolls (Temperatur) Annealing (Heater)
Autom. Sheet Width Adjust	Geometry Measurement	Cutter Bar (knifes) or Saw Longitudinal
Autom. Sheet Lenght Adjust	Geometry Measurement	Guillotine or Saw (transversal)
Autom. Good/Bag Segragation	Thickness Measurement Surface Inspection System Flatness Measurement Color Measurement Geometry Measurement	Stacker Side Segragation
Autom. Die Width Adjust		Die Width
Autom. Material Used Control	Weight Measurement	Dosage Unit

Once fully implemented the automation part one, the machine operators will be able to control and change production parameter at distance, only having to actually go to the machine at beginning and end of production or if something uncommon happen at the machine. This could increase the efficient of their work, because workers will be able to monitor from a control central several extrusion lines at once. The workers would have more a supervising function of make sure everything is being produced the way it is supposed to be. They will also be able to see through cameras the process live and with the measuring systems control the quality of the material. All this at distance, without being exposed to the machine heat and eventual process smoke. Also change production parameter from the central, increasing flexibility and saving time.

4.2.2 Automation Part Two

Data analysis is the main goal of the automation part two. After the part one is completed several measuring systems will be in place and generating lots of data. Until now the data from the sensors were being observed by the workers at the central and they were making decision based on the reading of the systems. However the data was not being collect and even less analyzed. Automation part two will face the next step of data collection and analysis. During the expert interviews two ways of data analysis were proposed as possible solution. The first is real live simulation. The idea is through physical models runs simulation based on temperature, material viscosity, pressure, screw speed and others, in order to find optimal processing conditions. The system would run calculations based on data provided by sensors as the machine is working; the system would simulate several different production parameter scenarios and compare to the currently being used. Once the system find a better processing configuration it would give a warming to the production supervisor at the control center. Then they would decide if the actually implement the system suggestion change or if they keep the production the way it is running.

The second solution discussed during the expert interview is the use of machine learning. The system would be taught, through large amounts of production data, how the production should runs. Also the system would identify, based in big data analysis, what were the production conditions that generated material failures. So it would warn the worker if the production parameters are reaching conditions where scrap is made. The system, once well implemented, would give suggestions to the workers on production parameter change. Then similar to the first solution, the production supervisor can decided, based on their experience, to change according with the system suggestion or just leave the configuration as it is.

The main topic of the automation part two is analyze production data, from the data generate suggestions to change the configuration at the extruder. Also to provide warnings if the machine parameters are such that have high probability to make scrap. However the system as mentioned by the compounder researcher at Das Kunststoff Zentrum "(…) are like a driver assistant system in a car, it tells the drive when to change gears. However here the system shows how should be the parameters at the extruder." The system will only assist the worker, helping them to make faster and more precise decision. Nevertheless the final decision and responsibility still comes from the workers surpervisors.

4.2.3 Automation Part Three

Automation part three is the final goal at a polymeric sheet manufacturing plan. Fully automation was the goal according with the experts. The extruder would self adjust its parameters in order to keep production inside desired tolerances. Workers will probably still monitoring it, but the production parameters will be decided by the machine. At part two the decision was from the supervisor, now the worker only monitor; but the machine is the one actually altering production configuration. A change in the decision making is happening, from the worker to the machine. Of courser, probably the employees still will have at all moment the power to overrule the machine if they see it fit.

Another characteristics of automation part three is the automated transport from the extruder line to the logistic department and the connection between suppliers and customers. The idea is that once a customers order is placed, also does the company order to buy the granulates and the information about the final product goes to the machine that produces it. Then the sheets go to the logistic where they are shipped to the costumer. A fully integrated information flow between suppliers and costumers, therefore allowing the precise knowledge of the data when the order is finished and allowing low material stock.

4.3 Machinery Customization

Not only should the future changes be highlighted, but also the things that will stay the same. In an interview with an engineering from the company Krasumaffei an interesting point was discussed as he mentioned: “No huge step regarding modifications at PVC extruders production process.” Here, he was talking about the screw and barrel design for increasing output when processing PVC granules in to sheets. It was discussed that the laws of physics need to be respected, and the currently state is already optimized to the material’s maximal shearing and perimeter speeds. He mentioned that the screw design is always being optimized, but only regarding small changes. Therefore he predicted not a big change in the area, as quoted above. The process is already well optimized and as observed during the interviews none expert predicts big changes in the area. The search will be for the small innovation that gives an extra edge on production, and that small advantage will have a big influence in a stiff competition market. Those small innovations will come from machinery development and also from the ways companies do business. Mostly important companies need to increase flexibility, using their employees with the machines in a synchronous mater in order to achieve higher flexibility with lower wastes.

4.3.1 Assembly the Extrusion Line in House

One trend observed during the interviews is that extrusion companies will start to select the parts and equipments for the lines from several different suppliers. Instead of buying from one supplier a complete extrusion line, the companies will buy just a few parts, the rest will be ordered with others machine manufactures. Later the assembly will be done in house, at the polymer extrusion company. The assembly will require some know-how and other skills. However the assembly of the extrusion line will allow the company to have more flexibility and to customize the machine to its exactly needs. Also has the potential to reduce the total investment, because simple parts can be manufactured at others companies at lower price.

4.3.2 Extrusion Output Capacity

The output of the machines is very important to the industry. It has a strong link with the final price per kilogram; and the drive to larger output machines comes from the market demand. It was seen that in the polymer sheet extrusion, most of the time what limits output is the cooling capacity and not the extruder output. Increasing the length between the die and the place were the sheets are stacked increases the cooling capability. Therefore the sheet will take longer to reach the place where they are stacked, increasing the time to cool down. The machinery manufactures already have the know-how to increase the extruder. However it was seen during the interviews that the increasing in output is not the goal in some areas. The output may increase only in areas with a high and constant demand of products. It was also observed that currently in some sector the equipments already have the enough output to supply the whole market; therefore those areas are searching more for production flexibility and reduce costs.

4.3.3 High Speed Extrusion

High speed extruders were point out for having a smaller barrel volume, therefore less melted material in its interior, however this does not mean less output capabilities. Therefore the can maintain the production output with less melted material in the chamber. This decrease the amount of scrap material generate when changing production from one material to another.

4.3.4 Modular Features

The optimization of the extrusion line is always a goal. The machinery currently used for industry's well known polymers is already much optimized. Therefore, according with the experts the industry should see only small changes regarding the extruder. The most changes will come on the processing of biodegradable and post consumer recycled. The equipments will have to adapt to solve new issues during the process of those new polymers. Therefore the material will drive the machinery changes. The production will implement special features to address specific problems and those features will be modular. So once the material changes, the extruder can be reconfigured to address the next production. This will increase the product range by giving more flexibility to production. An example is the use of a second feeding section in the extruder barrel, allowing more filler to be added to the melt. These two examples illustrate the idea of having special features to be used only when needed. Thereby improving the optimization of the machine for that product process; reducing cost and increasing product range. Later, when not more needed, the feature could be removed. Those modular features here presented are all material driven. That means that they can be implemented but what is going to determine that is the type of material being produced. The down side of using them is the need of more storage space and people to install them every time they are needed.

4.3.5 Sheet production with Two Rolls

Currently the production of polymeric sheets is made with the use of three stacks rolls that presses and stretches the material in to shapes right after the die. However there is the possibility of using two stacks rolls instead of three to avoid the limitations of the currently rolls stack. The material would be produced in straight line instead making turns going under and above the rolls.

4.3.6 Cooling Capacity

There are currently extruder lines were the bottle neck is not on the extruder. Sometimes the bottle neck is on the cooling capacity. In other words, production output is not increase because there is enough time for the material to cool down before it reaches the end of the production line. So it is still to warm to be packed. It was mentioned by the experts to make the production line longer. Therefore the material will have more time to cool down, allowing increasing the output production.

5. Discussion

The sector five of the work discusses all the results found during the interviews. The author goes through all the results and present some opinions about the outcome found during the interview. The technologies are each individually discussed, except the automation part. Automation is again showed in parts in order to facilitate understanding.

5.1 Energy Consumption

Energy consumption is a big trend throughout all the major industries. So this topic is a trend for development and improvement inside the plastic industry as well. In order to decrease energy usage new technologies are coming to address the issue. More efficient motor that convert electricity in work and ways to reuse some of the process energy are two examples. Two factors influence the implementation of one of these technologies. The most direct incentive to adopt one of these technologies is how much savings it will provide compared with the investment price. The higher the savings, shorter the period of time for the technology pays itself. Here the location where the production plan is located has a great influence on the decision of adopting energy saving technologies, because energy prices change from one country to another. Thus in countries with a very low energy cost the companies will not see these technologies as priority. The opposite is expected in places with high electricity costs. Global warming is another strong argument that introduces energy saving as a future trend. Throughout governmental plan and certificates, companies will have an extra incentive to adopt energy efficient technologies. Since most of the electricity generation grade of the countries is a mix between renewable and non-renewable, there are always greenhouses gases being introduced in the atmosphere as energy is generated. So other incentives will have to be implemented soon or later to increase the energy efficient usage. These incentives could be through taxes or certificates. Government laws could reduce the taxes by the company during the time of paying investment. The companies that adjust to these laws receive tax incentives, the ones how do not, may pay extra fees. In order to receive them, an efficient energy usage is required. The certificates, on the other hand, help the company to place its products on the market. Because they prove that the company is aware and worried about those global issues, so the products have a stronger marketing appeal. So it is easily seen that are a few factor playing different roles on the decision of investing in energy save technologies; from the paybacks time, to governmental energy laws and the production location. Which this means is that some of these features will make sense in so countries and in others not. Also that once new energy saving polices are applied these technologies become a lot more attractive. However the future of energy polices along the world is very complex. So the exactly time that these features will become economically viable can be difficult to estimate. Nevertheless, it is a fact the energy saving is an important trend throughout the manufacturing industry, that includes the polymeric extrusion sector.

5.1.1 Higher efficiency electrical engine

This was one of the solutions found in order to decrease energy consumption. It is a simple solution and easy to implement. Not requiring testing, special knowledge and much time to implement. Also since most of the energy introduced in the process comes from the screw, which is driven by the electrical engine, every percent gain on the engine efficiency is almost the same percentage in overall savings. Here the amount of hours the engine is used in the month also has influence in the haste to implement more efficiency motor. Electric engines that are constant used will have a greater priority to be substituted than the ones rarely in operation. However, it is a fast way to reduce energy consumption so is something that should be seen during the next years.

5.1.2 Pre Heating of the Material

Pre heating of the granules before they enter the extruder decrease the amount of energy that enters the process. Since the material would come at a higher temperature as normal, it would need less torque from the screw, therefore less electricity. The process to reuse the energy from the process to pre heat the granules is relative new. There are solutions on the market today, but all are still relative complex and expensive. A company called SHS plus has already developed a system that can reuse some of this excess energy from the process to pre heat the entering material. Something else to point out is that this technology will make more sense and work more efficiently in cold weather countries. “It makes sense in cold countries where the granules comes to the extruder at a low temperature. In warm places this technology will no present the same efficiency”, master worker at Institut Für Kunststoffverarbeitung. What this means is that the temperature gradient in warmer countries is smaller, so the heat transference is less intensive. Diminishing the amount of energy the system is able to bring it back to the process. Therefore making the system less efficient and possible not making sense the investment.

5.1.3 Direct Drive

A direct drive eliminates losses at the transmission of torque from the motor to the screw. Since it eliminates the gearbox, transmission belts and gears, it is able to cut off their losses. Also by eliminating those parts mentioned above the overall investment on machinery could be reduced. The technology for the direct drive is already available. Breyer extrusion lines and EMF Motor already have available direct drive motors. The advantages of a direct drive do not stop only at energy saves and reduces in extruder parts investment. According to Rauwendaal (2014) noise is decreased because there is no torque transmission, so working quality increase. Also maintenance reduces since there are less moving parts to wear. These extra advantages can be others reasons other to justify the use a direct drive engine.

5.1.4 Heat and Friction Optimization

In the production of plastic sheet there are two ways that energy comes in to the process. Either by the screw or by the heating elements. Monitoring the energy intake by each of them is important to process optimization, because most or even all of the energy introduced to the process should come from the screw. This provides a more stable and less scrap production. So even that the range which an energy monitoring system can actually decreases the consumption is limited, because it only monitors. The system provides information that allows to improve the stability of the process, reducing scrap.

5.1.5 Decrease the Number of Steps Process

The greater the number of steps the material goes through, the greater the amount of energy used in the production. So it is important to process the material with the fewer number of steps as possible. “A process from powder direct to melt…” educational researcher at Das Kunststoff-Zentrum. The possibility to decrease the production steps change for different material. Because there are some polymers types that currently require more steps. Thus this approach of reducing process steps can be implemented only until a certain degree. Also it can be that the machinery required to process the material in fewer steps is not worth the investment. For example, if a company has a single screw extruder for a product that is feed with granules. It can be that this machine would not have enough mixing and dispersing power to provide a homogenous melt when feed with powder, so the raw materials from the recipe need to be compounded beforehand; adding one step. Then it can then be normal processed at a single screw extruder. So if the idea is to reduce one step the investment of a new extruder with greater mixing and dispersing power is necessary. The investment of new equipment can be too high not generating enough saves in energy to make it worth. However for companies with large quantity production may justify the investment in new machinery.

5.2 Automation

There is not doubt that automation is going to provide great benefits to the manufacturing industry. The benefits of automation are vast and essential to keep and increase competitiveness at a company. However now the questions is how to reach automation. During the interviews the experts showed similar answers for the next step. However, steps further showed divided opinions. The truth is that there is not a standard path to reach industry 4.0. The work from Matt, Modrák and Zsifkovits (2020) show that there is not a clear path to how manufacturing facilities can reach industry 4.0. During their work they consult several industry manager and leader from several manufacturing sector and different countries in a two years project to establish challenges, opportunities and requirements for small and medium size companies. They collect requirements from the interviews and questionnaires about what does the leaders want to improve with automation at their companies. From that the authors were able to draw a course guideline of the functional requirements to design smart manufacturing systems. The present work was realized specific for the polymer sheet extrusion manufactures. However methodology used can be related to the work of Matt, Modrák and Zsifkovits (2020), mentioned above. Both works interview expert and industry leaders to collect data. The data provide industry needs on what should be automated. Here is where is going to be important of industry experts working together with software engineers and IT specialist, in order to better explain the exactly needs of the manufacturing company and design tailored solution for it. However the present work, since is delimited only by the polymeric sheet extrusion industry, it was possible to specify systems and machine parts that need to be implemented. Therefore the results can be more concrete and structured, providing a guideline to the industry on steps to increase automation. Allowing the reader to have a more concrete view of the automation process and the machine parts and systems required for sheet manufactures. Nevertheless the future is volatile, uncertain, complex and ambiguous (VUCA), so the result from this work can vary in some degree from the actual path that the extrusion companies will take. Automation is a relative new concept and papers are currently being published about it. The research institutes are working on solutions as well as companies. The specialists will have to provide custom solution to deal with those peculiarities. Since the needs are different, the path to automation also changes among the manufactories sectors. So since no path is established yet, and different companies are trying different things, now it is a great opportunity to, with help of industry expert, draw some guide lines of how the automation process should take place. Several companies will try different approaches and some will work and others not. Big tech companies will develop automation features and some will become industry standard. Once good results on automation start to show up, other companies will follow the same path, then the path will become a standard.

5.2.1 Automation Part 1

The main characteristic of automation part one is the workers being able to monitor and control several machines at once and at distance. At part one in automation the idea is to substitute all the hand manual levers, hand wheel and etc. to hydraulic, electric or pneumatic system that could be electric operate by distance. Also the systems through sensor and cameras can monitor all the quality parameter, like color, thickness and geometry. Thus the goal of part one is to make the monitoring and control of production more efficient and comfortable for the worker. Once implemented the quality of the sheet can be observed through monitors and measurement system, so the worker does not need to stay close to hot surfaces, for example when the bank is visualized. Also parameters from several machines can be visualized at the same place, making it faster and more efficient than having to go to the line to check it, making it necessary to go to machine only on special occasions. Consequently, it can be seen that part one is in summary visualization. By observing the whole process from a distance and monitoring the production. Here data collection will also be a big part, allowing for later data analyses.

The advantages of automation part one are faster analysis of bad production and agility to fix by having all the controls at one place. However one disadvantage is that the full benefits of automation part one can only be enjoyed once all the systems and machine parts are implemented according with the results. If realized in an incomplete way just some benefits will be provided, also the workers will probably have to stay at the machine, as is today. Therefore the workers efficiency will stay constant, and perhaps not justifying the high investments necessary to implement the systems.

5.2.2 Automation Part 2

After the measuring systems and cameras are installed at the extrusion line it is possible to start thinking about data collection and analyses. At part two is where data start to provide some information and some decisions can be make from it. The idea is to optimize production, prevent mistakes, predictable maintenance and reduce starting production times. Here for the first time the machine/system starts to give suggestions on production changes. By processing the data collected from the systems on part one it is possible to draw conclusions about the production. Therefore take some data drive decision. Important to point out that from processing and analyzing data only suggestions are generated but the decision on actually implementing them or not still from the worker. He has the final voice on deciding to adopt or not the production condition provided by the system.

The concept of how should work is as mentioned above, however how it work it is still for debate. The processing of the production data and generating value information from it still not clear. There are two main paths that were mentioned by the experts, simulation and machine learning. Simulations are based on simple physics models and have been providing value information on machine manufactures since the 80's. With information from the material properties it is possible to run live simulations in order to optimize production parameters. The advantages are that is a feature already known for some time and of not high complexity. Therefore is it simpler to implement then machine learning. Machine learning on the other hand present greater complexity. It is a technology that still being developed but presents promising advances in manufacturing industry. Today is being used mostly in technologic companies as prototypes. However since its large possible advantages the whole manufacturing industry have interest on it. The plastic industry also sees it as a promising technology but probably will actually invest one it once the technology is more mature and when it shows clear advantages to the sector. It is not though that the polymeric sheet extrusion will be one of the first to implement machine learning at their manufacture facilities. However this technology is something in the experts mind as a future feature to improve automation. The idea would be to teach a machine based on large amounts of data how to produce a product. Once taught the machine would be possible to manufacture that material without or reduced workers interference or similar to simulation, provide suggestion on how should the production runs to optimize time and resources.

The overall, once implemented, of the part two would be a production where large amounts of data are collected and processed. Through data processing the system would provide suggestion on how to optimize production. Then workers could chose to implement the changes, thus making data driven decisions, improving decision making and saving time. Or the workers could decide based on experience, to keep production as it is. Nevertheless they would have more information to make decision and therefore improving decision making.

5.2.3 Automation Part 3

The concept present at part three is a shift of responsibility. Until now in the automation process there are large amounts of sensor and cameras collecting data. The data were analyzed and value information was generated. Yet, the information was used to improve decision making. At the final part of automation as the data from production is analyzed the decision are being made by the machine onsite in order to keep the process at its best. There is a transition in decision making from the worker to the system. The workers still observing the overall production and parameters, but they may only interfere once a problem occur. Probably some type of responsibility transition will be seen. Once the system prediction ability becomes good enough it will make machine production changes without consulting employee. Of course, this transition will be gradually and probably will still always have someone monitoring the system activities.

Other features is the completely automation of production planning. The orders would come directly to the machine, later it would produce the order according with the specification and transport the product to the logistic department. There the material is shipped to the customer. Material stock and production time all integrated.

5.2.5 Automation risks

The experts interviewed all demonstrated very optimist views on the automation topic. Not a single one present concerns and discussed about the risks of automation, like high investments cost, reduced in jobs and decreasing in expertise. However there are several published works on the risks of automation, specially reducing labor force. Jeremy Rifkin (1995) in his book "The End of Work" express concerns about the benefits of automation not being shared with the workers, only the stockholders enjoying the advantages. Therefore increasing the wage gap between low skilled workers and managers, squishing the middle class and creating a divided society. Also Amaldi and Smoker (2012) present concerns regarding wrong automation design resulting in workers being overloaded and the slow down in expertise development. Interesting to be observed is that none of the experts interviewed showed any concerns of any type. Therefore this shows that they are confident and optimist about the advantages of automation and are not worried about the risks. Perhaps the main reason for risks not showing up during the interviews is that all the interviewed work in some area of research and development, engineering, material development and management. Thus, their main job focus is to improve the company competitiveness in their specific area. Therefore they do not show concerns regarding jobs being reduced but they do present concerns about the challenges on how to implement automation. This can be seen on an engineer from Krauss Maffei when he mentions as a trend to the future "the challenge now is to connect everything: suppliers, machines and clients...". It shows a concerning on the technical side of the automation problem. The experts interview are more concerned on how to do it than on possible social problems generated as consequence of automation. This is justified because once they do not increase their company's competitiveness and do not utilize the "Industry 4.0" advantages their competitor will. Consequently, their facilities will lose competitiveness, market share and possible close, putting their and their colleagues jobs at risk.

5.3 Machine Customization

Machine customization is the third cluster of this work where is discussed machine optimization and trends in the extrusion equipments.

5.3.1 In house assembly of the extrusion line

The idea is the in house assembly of the extrusion lines. A behavior change, instead of buying the completely line, it would be purchase the parts separately. Today what often happen is a company buying a completely extrusion line e. g. Then the supplier assembles the whole machine, with all the parts and delivers a ready solution. It is convenient to do so and the line most likely will run just fine. However there are advantages when the extruder parts are bought separately. The first gaining by separately buying the machinery parts is the greater degree of freedom to innovate and custom optimize the line. This method allows companies to select specific parts that they would like and implement them. By doing so, it is possibility to analyze each and every one of the parts. The company producing the extruded products can select the parts from several suppliers according to its specific production process, reaching a greater optimized final assembly. “Extrusions are already well optimized, now we are looking for those last percentages”, head of process development at SIMONA. This deeper analysis of each part to provide a better optimization can be those last percentages as mentioned in the quote.

Another advantage is that the innovations stay in house. Innovations at the extrusion line often come by changing parts and equipments to improve production. However when ordering a new extrusion line, special changes on it are charged extra. There reason is that the machine suppliers need to redesign the part changed, implement it and alter the instruction manuals, so extra worker hours are needed. Thus they have extra spending when altering something at a line compared with only supplying their standard equipment. As the innovation is made the new line is delivered. However once that new change proves to be effective the machine manufacture gets the knowhow. This mean that the supplier responsible to assembly the line will gain the knowledge and at the same time charge extra for the innovation. Then later, the machine manufacturer can easily implement the change and apply on the future order from other companies. In the end the extruder company that generated the optimization will have their competitor using the same technology as the one they developed. Consequently diminishing the advantages from the companies how developed compared with its competitors. So buying the parts separately allow the knowhow to stay inside the company. At the same time when assembly in house it is possible to standardize all the machines electrical part. Therefore the human machine interface can also be the same throughout the line, facilitating data collection and storage. Thereby, facilitating the automation features to be installed. Since the electrical cabins and controllers are standard in all the machines.

Another advantage by selecting and assembling the extrusion line in house is reducing machinery investment. Perhaps this is the most important benefit. Once developed the engineering knowledge is possible to go to others manufactures outside the plastic industry for the parts manufactory itself. Probably complex parts like the die and screw are still going to be bought by specialized companies, because these parts require greater knowledge to produce. However the simple parts like rolls calenders and extruder chassis could be manufactured by companies outside the plastic sector. Thus the final machinery capital investment is lower. “Initial Investment is a big thing in the future”, again head of process development at SIMONA. However the suppliers of extrusion lines are aware of the need to decrease the equipment price. “Price of the machine needs to go down to stay competitive”, research and development process engineering at KrausMaffei. As seen the machine suppliers are aware of the necessity to decrease their equipments cost. Because reducing the initial investment in equipment increases the company’s competitiveness and shorter investment payback time. Thus there are extruder manufactures companies already working on different business models in order to address this issue. Solution like renting machines for specific season of high production and later taking the machine back and reselling or renting again are already being implemented by KraussMaffei (K-MAGAZIN, 5/2018).

5.3.2 Extrusion Line Output

The extruder size is dictating according of the production output required. Years ago there was a big rush to make bigger and longer extruder. To always increase output and length diameter ratio. However this changed. “The future is no increase output, there are many applications where the output of the machines are bigger than the world demand”, head of research and development at Renolit. Therefore extrusion should only still increase in applications where the demand is large and constant. Today the method use to increase output it to enhance the diameter. However if the diameter is increased, also is the volume of melt material in the barrel. That means that every beginning and ending of production will generate more scrap, which is not a trend. Therefore, as mentioned, the output shall increase only in areas where there is large and constant market demand. Otherwise, the investment will not be worth it.

5.3.3 High Speed Extrusion

For the future, smaller extruders, with smaller interior volume are promising solution. The amount of scrap generated every time production starts and ends is reduced, because the melt volume is smaller. They could allow production of smaller batches with different color, shapes and materials, consequently providing more options for costumers. High speed extruders present the characteristic of reduced size with same or larger output. Today high speed screw extruders are not suitable to all the types of polymers and application. They can be used in non-sensitive plastics as polyethylene, polystyrol and polyamide (OSSWALD; BAUR; RUDOLPH, 2019). But once screw design is optimized the range of polymers possible to be processed should increase. The smaller machines also could be considerable cheaper than big ones. Because of reduced manufacturing time, material and transport costs. Therefore high speed extruders have the potential to increase production flexibility, reduce wastes and reduce investment cost; making them a potential equipment for the future.

5.3.4 Modular Features for New Polymers

New challenges will appears when processing polymer like biodegradable, bio based and post consumer recycled. Since they are not being processed for as long time as industry well known polymers like polyolefin and PVC, they have a greater gap of improvement. In order to address the vast types of polymeric materials some features needs to be implemented. Those modular features could increase the production flexibility, by implementing special features addressing the production needs. Once the production changes to a different material also the needs change. Then those modular features could be easily implemented or withdrawn. The extruder will be able to be prepared for a production of a different material with only the addition of those modular features. Allowing smaller production bathes and higher customized products.

5.3.5 Production of sheets with two rolls stack

Today the common way to produce polymeric sheets is to melt the material in an extruder, pass it through a coat-hanger die and after through a set of three rollers. During the interview were discussed the possibility to use only two rolls. This would allow the material to be processed in a straight line instead of going under and over the middle roll and later over the top roll. In the currently configuration the material makes the two 180° turns to contour the rolls. Eliminating the turns would provide two advantages. First that for foam and thick sheet the core of the plate would not be sheared, consequently providing a more unbroken foam core; because the material stays straight throughout the whole process. Second the material would be able to being processed at higher temperature without unsticking from the rolls. Increasing the process temperature is possible to increase the output for some of the polymer sheet types. Because sometimes the production bottle neck is the rolls stack and not the extruder. However this is something that none expert were able to properly answer. Therefore more studies on the topic are recommended to evaluate the viability of producing sheet with only two rolls.

5.3.6 Cooling Capacity

As shown, sometimes the bottle neck of production is on the cooling capacity. Making the production line longer was a solution presented by the experts. It has show to work and allows the increase in output. It is a relative fast solution to implement, because more sets of rollers conveyors can be added. Making the whole production line longer, allowing the material to cool for a longer period of time. However this approach is only valid and easy if the company has the physical space to increase the length. If not, a bigger production facility it is needed in order to increase the length of the material cooling area. For companies how have this problem it is possible to cool some of the rollers in the roller conveyor. Therefore, forcing cooling on the material. The disadvantage is increase of energy consumption.

5.4 Limitation of the Work

All the experts interviewed were from Germany, therefore could it be that in other countries the trends may vary in some degree. Also an important fact that influenced the work is that most of the experts interviewed are from the polymeric extrusion technology or institutes that research about the topic. So they all share similar ideas about the future. By having similar views it can happen that not all the options for future technologies were collected. Therefore, the result from this work can be incompletely or even different from what we will actual see for the future technologies in polymeric sheet extrusion. This is consequence of most of the experts working in the same sector of the industry, the plastic process industry. Even that during the interviews data saturation was reached, as was seen by the last interviews where no new ideas were provided. The questions of whether the data is incompletely or not, still remains. The data can be questionable regarding its fullness only if a new technology comes from an industry outside of the plastic industry. Because if new technologies come from another sector of the industry and the experts interviewed were not aware of that, then this work would not be able to predict it, because it was not collected as data. Automation is the most probably cluster where a new technology could be developed outside the plastic sector. However, it was shown that the experts are very aware about the large changes in the manufacturing industry regarding automation, industry 4.0, digitalization. And even that the technology development of industry 4.0 comes from others sectors of the industry, the plastic industry is well aware of its advantages. Also the experts by working together with those developers can better show the needs for the plastic sector and guide the way to automation. Therefore, it is not expected that the interviews left outside a big idea regarding automation possibilities inside the polymeric sheet extrusion sector. Since the experts are the ones better suited to guide the way from manual process to automation. Outside industries have a low probability to develop technologies specific in the extrusion field. The main reason is that knowhow it is necessary to make innovation. Innovation is developed where manufacture is made (BERGER, 2013). Therefore is a lot more probable that the experts in the plastic industry guide innovations in the field instead of outside specialists. Also all the experts mentioned automation during the interview, showed that they are completely aware of it. The other two clusters follow the same principal, where the extrusion experts are the ones most likely to provide innovations on the sector.

Another fact that could make the results from this work not correct is the market. The market could demand a new product that requires a new production method, consequently creating a new niche that the plastic industry will enter to supply the demand. So the developing of special machines and processes for the new product or field it is an option in this scenario. However product development was not covered on this work. The work focused on the new technologies for the production process used today. So the possible changes in machines and process driven by new products are not part of this work.

6. Conclusion

The future is uncertain, so it is not possible to list the precise new features that will be implemented in the future production of polymeric extrusion sheets. This work however, concluded that three are the main areas of improvement in the polymeric sheet extrusion production. They are decrease in energy consumption, automation and machine customization. These areas of improvement are likely to be the future, because the people interviewed are working today in developing these technologies. Therefore it is plausible to be seen these features in the industry in the next 10 to 20 years.

The topics found to be the future technologies in the extrusion of polymeric sheet are presented in this work in an organized way. The work can be read by manager and anyone working in the area and the results can help them to understand what to expect regarding of changes in this industry. The three main cluster of improvement can orient investments direction, helping the industry leaders to select the right investment according with theirs strategies.

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Annex A

Description of each function on table 1.

Automatic Recipe Setting: The ability to change the proportion of the granulates entering the extruder. Therefore control the amount of each material entering the hopper of the extruder. The dosage unit is the equipment that regulates the amount of each material entering the process.

Automatic Die Adjustment: The die can be adjusted with two mechanisms, the lips and T/R (choker) bar. The lips control the flow in specifics areas of the sheet and the choker bar control the amount of material throughout the whole bright of the sheet. Both are adjusted by screws.

Automatic Thickness Adjustment: The ability to change the thickness of the sheet. The gap between the rolls stack is the main factor that influences the thickness.

Automatic Back Control: The bank is the melt material that forms before the first set of rolls. For some material the bank is important to assure a good sheet. The bank must have a certain size and the size is mainly controlled by the rotational speed of the stack rolls.

Automatic Flatness Adjustment: This function represent ability to adjust the slightly curve that the material can form as is being processed. The flatness of the final sheet is controlled by the difference in cooling rate between the top and the bottom of the sheet. So a control of the stack rolls temperature, annealing heaters and temperature pressure rolls allow for an adjustments at the material flatness.

Automatic Sheet Width Adjust: The material is always extruder a little wider as the final width desired. Then the edges of the material are trimmed off because they do not have the same thickness as the rest of the sheet. The cut is performed in the extrusion direction and can be by knifes or by saw, depending on the thickness of the material being produced. So this cut defines the final width of the sheet. Changing the position of the knifes/saw can slight alter the width of the final product.

Automatic Sheet Length Adjust: A cut transversal to the extrusion direction defines the length of the sheet. By altering the time of the cut the final product can be a longed or shortened.

Automatic Good/Bad Segregation: This function is responsible to automatic detect and segregate the parts of production outside the tolerance, the scrap. Here the measuring systems are fundamental. They detect the fails along the sheet. Then the information is shared with the stacker, finally the stacker pill the scrap material at a different pile. So the scrap is automatic segregated from the final products.

Automatic Die Width Adjust: Some dies can produce several different width sheet only by changing their edges. The idea is the use of a wider die than can have its edges automatic altered. Therefore between production orders with big width differences the die can have the edges changed to properly produce the next production order.

Automatic Material Used Control: The thickness in which the sheet are produces usually have a tolerance of +/- 0.01mm. Therefore, even that small, along several tons produced the amount of material produced it change between production orders of the same sheet. The idea is to use a scale at the end of the line. The scale would measure each sheet individually. So a precise value of the amount of material used will be available to control stock. Also in foam material the density can be monitored during production.

Annex B

Thickness Control

The thickness of the material produced is controlled by a few parameters at the machine. These parameters are the opening gap of the die, lips of the die and gap between the rolls. Each parameter regulates the final thickness of the sheet. Today adjusting these parameters is hand made by a worker. Some of the parameters have leaver and wheel that need to be presently operated by a worker. Therefore to be able to automat first it is necessary to substitute those leaver and hand wheels to systems that can be remote operated. For example: hydraulic, pneumatic or electric motion systems. After the machine is completely ready to automation, that means no systems exclusively operated by hand, them repetitively tasks can be automated. The combination of all of them results in an automation thickness control.

Opening gap of the die: The opening of the die regulates the amount of material that comes out of the die. When a larger gap is used, more material lives the die in the same time period.

Die lips: In a sheet extruder die there are two lips that can, until some degree, adjust the material flow out of the die. The lips gap can be tuned to allow more flow of material in some areas and less in others. Therefore it has the ability to control the thickness in specific areas along the sheet. It adjust the profile of the sheet. This is a function totally adjusted by hand. A worker turn screws at the die that gently bend the die lips. However there is a automation solution for this task. The maku die tool is a feature that turn the screw at the die adjusting the die lips and T/R-bar . The maku die tool is a patented technology and is brand new feature. It has great potential to be the solution for the automation of the die lips and T/R-bar.

Rolls calender gap: After the material leave the die it goes through three rolls. They are called rolls calender. When the material passes at the rolls it still in a high temperature and can be easily shaped. The gap between the rolls limits the amount of material that goes through. Also gives a thickness to the sheet. The gap can automatized with the use of electric linear motion. Therefore the gap can be adjusted only pressing a buttom and later integrated to a system can gives the order to tune the gap.

Thickness measurement: The thickness measurement is the system responsible to measure the sheet direct at the line. There are different technologies that can be used to measure the thickness of the material being produced. A few examples are triangulation laser sensor, terawaves and LED profile sensor. Each thickness measurement method has its advantages and disadvantages compared with the other systems. Regardless of technology chosen, the important is to have a precise and reliable measurement of the thickness. Because once that the system know what is the thickness of the material being produced the others systems parameter mentioned above can be adjusted.

Color control

First off all it is necessary to measure the color. This can be achieved by the use of a color measurement sensor. This sensor is capable to measure the color in values of L, a and b. The L value goes from zero to a hundred. Zero is dark and 100 bright. Positive values of a are red and negatives are green. Regarding of b, positives yellow and negative values are blue. So a color can be measured in those three values: l, a and b. Then the color information can be passed to the automatic feeder and the right amount of masterbach can be adjusted.

The color is given to a product with the use of masterbach. Masterbachs are pigments and/or additives encapsulated in the polymer resin. The resin and the pigments/additives are disperce in the polymer resin and cut in small pieces, the granules. Those granules are the masterbach. They are responsible for the color. Varying the amount of it the color can be changed.

Controlling the amount of masterbach the color can be controlled. An automatic feeder allows the dosing of the right amount of masterbach in to the extruder hopper. Assuring a constant color during the whole production.

Dimension Control

A polymeric sheet has three dimensions. The first is it thickness, already mentioned. However length and width also need to be controlled during the production. These two dimensions are controlled by the edge trim, the saw or guillotine and the die width. The die and the edge trim provide the width of the sheets. The die gives large width adjustments. So the width of material the lives the die are changed when is necessary a big width adjustment. On the other hand the edge trim provide small adjustments. It cuts off the edges of the material parallel to the material processing direction. The edges do not have an uniform thickness and needed to be trimmed off. The final product consists of the central part only. So the edge trim and the die regulates the width of the sheets. The saw or guillotine cuts the material in the transversal directions. Thus giving the sheets length. Therefore to control the length and width the die and the edge trim along with the sheet transversal cut needs to be controlled.

Today the measurement of the sheets dimensions is done by a worker with a measuring tape. It is a task very repetitive and the measurements are not made in every product. So when implementing an automatic geometry measurement it would gain two advantages. First one is eliminating one repetitive and boring task to the workers. At the same time increasing the precision of the measurement. The second advantage is that all the sheets produced could be measured. Thus, increasing quality control.

Surface Control

Each product has tolerances regarding surface defects. The defects are any heterogeneous surface appearance. They can be texture changes, color variation, hard spots and scratches. A worker visually inspects each sheet and looks for those defects. In opaque material the defect inspection is only possible at the surface. However in transparent it is possible to perceive internal defects with visual inspection only.

The task to visually inspect individually the sheets is time consuming. It also requires training for the worker to be able evaluate can classify the defect. The defect can be critical, half critical or almost an error. The classification is based on company internal standards but it can have measurements deviations between different workers.

A surface inspection system is an alternative to automate the surface control. It is a system that emits two sets of light to the material. One light is reflected at the material surface and the other goes through the material. The first light is emitted at the material surface and sensors capture the reflection. Then a software analyses the light captured and detect deviations. Those deviations are surface detections. The second sets of light works in a similar way but the light passes through the sheets. Then sensor captures the light and the software analyses it. Black spots inside the material can be detected because they generate shadows at the light beam.

The system can be adjust to better detect what is a defect and what is not. After the systems software is well adjusted to classify the defect a standard measurement can be achieved. The advantages of using a system like that are: the system will always evaluate the defect in the same way and workers do not need to be trained to execute this task. Also the system free times for the machine operates to execute more important activities.

Temperature control

Today the temperature measurements are at the machine. The machines have several thermal couple at different zones along the barrel, die and rolls stack. The completely temperature control is made at the machine. It is a system that works but has some limitations. Since the thermal couples are measuring the temperature at the machine, the temperature at the material can be only estimated.

A good temperature control of the material increases the product quality. Because instead of monitoring the temperature of different parts of the machinery, the temperature of the material itself is controlled. It allow for better understanding of the cristalinization process, internal residual tensions and the cooling ratio of the material. Once all these phenomena can be visualized the machine driver is able to better tune the temperature at different parts of the machine. Finally achieving a better optimized and stable process.

Bank Control

Bank is the excess plastic melt that forms just after the material leaves the die and before it passes through the first roll. A proper size of bank before the rolls stack is essential for a good production. A bank too small can lead to ripping the material and restarting production. The opposite can increase the thickness of the sheet in the central area.

The size of the bank is important to a stable production. Monitoring it can be done with the use of cameras. A set of cameras capture images from the side of the rolls stack. At first the images are displayed in a monitor. So the worker can visualize the bank size without getting in the warm zone close to the die. Already improving working quality.

A furthers step would it be to measure the amount of melt material in front of the rolls calenders. This could be achieved with image analyses software. The cameras from the side capture the images, send to the software that measures the bank size through the image. Later with the size information the rolls speed can be adjusted. As well as the screw speed and die gaps.

Bowing Control

Bowing is how straight the sheet is. Since it is a polymeric material, the final product present considerable elastic deformation. That means it can easily bend because of its low young's modulus.   Also the thinner the sheet, greater the deformation possible in the elastic zone. So by only placing the sheet against a wall it is possible to see elastic deformation.

However the important bowing during production is another. During the manufactory the goal is to achieve straight sheet. That when the product is place on a flat surface, the four corner and the middle of the sheet are in contact with the same plane.

To control the bowing the cooling rate needs to be monitored. The cooling should be controlled until the end of the extrusion line. Because the deflection can occur even after the sheet is placed on the pallet. When one side of the place cools faster than the other can be that the plate is bent. The reason is that once a surface is cooler that the other, tension from the shrinkage shows up. Those tensions can be strong enough to generate permanent deformation. Also know as plastic deformation.

Mass Flow Control

Mass flow control measures the amount of all material that go in to the extruder. Then later it measured the individual weight of each sheet, just before they are piled up in a pallet. The mass flow has some important advantages. First it can indicate with precision the amount of scrap being produced. Therefore, provide information about the amount of material that was grinded in the recycling process and come back to the extruder. Second it helps the control that all the materials are actually being feed in to the extruder at their exact amount.

Using a gravimetric feeder is possible to control all the material going in to the extruder. This helps the workers because when a material needs to be administrated in small scale usually is done by hand. That means that every 30 – 60 minutes the worker needs to go there and check if still material at the hopper. That consumes time and is a boring repetitive task. Also can happen that the worker forgets to check and the machine runs a period of time with the hopper empty. Since those materials are administrated in very small scale, for example fire retardants, the machine continues the production without a visible problem. However the final properties are changed, they just are not visually detected. Thereby the production is outside tolerances and since sometimes is not noticed the material can be sold as good material.

The second feature to be able to have a completely mass flow control is the individual weight of the final products. Weighting individually the sheets provide information on the exact amount of material used at each sheet. There are always small deviations in the thickness, length and width. Because there are tolerances to these dimensions. So the weight of the sheets always change. The weight changes among the sheets is small. However, along a big production where the machines runs nonstop for weeks, the difference from the material used and the calculation can be in the tons. Therefore this features allow precise information of the material consumed by a production batch. Permitting a better control of material stock.