SEPARATING PROCESS STEPS
LEADS TO NEW FOAM EXTRUSION MACHINERY

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Abstract

The consumption of resources can only be reduced by not using them at all. Therefore foaming is the key technology of the 21st century. Life Cycle analysis confirm this view: foamed oil based polymers are equal or better in carbon footprints compared with non-foamed bio-polymers. As a result, more and more research is dedicated to foaming technologies (injection molding, autoclave, rubber foaming,...). Only in foam extrusion, the most common and since 50 years industrial successfully used technology, still only is able to use a few polymers. In the last 25 years, only PP and PET material developments have enabled to use these polymers on top of PS and PE.

During the same time period, the only new machine development was the use of twin screw extruders, that have been substituting single screw extruders in foam tandem lines, as the twin screw extruders have shown major advantages using CO2 as blowing agent in the XPS insulation board industry.

When in Europe due to the reach regulation since 2015 new fire retardants ("FR") must be used, now even the twin screw extruders show disadvantages: the higher speeds, that enable better mixing, is increasing the melt temperature, which is critical above 190°C, leading to thermal degradation of the FR (bio-polymers are equal to FR) - as a result twin screw extruders are running less than half speeds.

The solution is to separate the process steps melting from mixing. The Gneuss MRS PET recycling extruder was further developed as a mixing extruder that is replacing the connection pipe between primary extruder and cooling extruder (or static coolers).

As a result, melt temperature is below 190°C, blowing agent is much better dispersed so that lower densities with similar product properties can be achieved. As well the process pressures in the system can be reduced, enlarging the process window.

Introduction

The biggest application of extrusion foaming is the production of insulation boards. While other extrusion foamed products are made by a variety of different extrusion technologies, insulation boards are mainly produced on tandem extrusion lines. Only a few machines have static coolers instead of cooling extruders, mainly made in the early years - with thicker boards, more output is needed to produce "thickness" which only cooling extruders can give.

Machine technology today

The primary extruders of these tandem foam extrusion lines are extended in length compared to regular extruders: a "regular" extruder, in which the solid ingredients (material, color, nucleant, flame retardants,...) are processed, an extension is added, in which the blowing agent(s) are injected into the melt and the material recipe is mixed. Single screw extruders are having a process length for example about 32 to 36 L/D compared with 24 to 27 L/D of regular extruders.

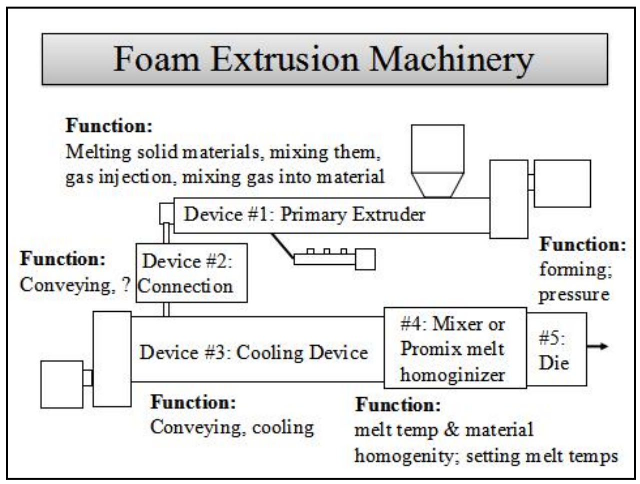


Figure 1: Process functions of foam extrusion machinery

One main target in foam extrusion of is to keep the melt temperature low. If flame retardants are used (Polystyrene "PS"), melt temperatures are requested to remain about 190°C (new flame retardants in Europe) to 200°C (HBCD flame retardants). Even if no flame retardants are used, temperatures should remain low, as the foaming materials have elongated polymer chains that allow better foaming - and these longer chains are sensitive against shear and high temperatures.Moreover, in average 35% of the material comes from internal recycling, containing regrind that has been internally recycled in average 5 times and as such was stressed significantly.

The melt is then transferred into the second extruder.

Here the melt temperature is being reduced: the blowing agent has significantly reduced the melt viscosity. Without increasing the melt viscosity by dropping the melt temperature the melt would not have enough resistance to withstand the bubble expansion of the blowing agent behind the die. If e.g. CO_2, that has the biggest foaming / expansion pressure, is used as blowing agent, the final melt temperature needs to b dropped to about 110°C.

Some research on small and medium output production lines has been made, showing that the melt that exits the cooling extruder varies from screw to barrel by more than 20K. To compensate, a mixer is used behind the cooling extruder. Most mixers are followed by a "sleeping tube", as the mixers are too short for thermal homogenization. Making them longer would created significant pressure drop, that most extrusion lines can not overcome, so that the sleeping tubes help to uniform the melt temperature a bit more.

Insulation boards are produced on flat dies. The exiting gap mainly is a slot (PS, PET), but for some materials, a perforated plate is used (PE, PET, SAN).

The "Cross Over"

If the pressure drops too much before reaching the die, the blowing agent would vaporize before exiting the die and the bubbles would be crashed when forced through the die gap so that no or bad foam products would be obtained. If a machine design does not allow to control the pressure or to built up pressure, pressure drop must be watched carefully. The most critical area here is the connection between the 2 extruders ("cross over"): to allow maintenance work, a spacing of minimum 1 meter is required, that has been extended now to more than 2m.

This connection has been mainly a heated pipe. A pipe is causing a significant residence time distribution: the material in the middle is flowing 10 times faster than the material at the side. This leads to mechanical and thermal de-mixing. Thermal critical materials like the flame retardants can be stressed significantly. As well blowing agents are de-mixed, so that in best case more blowing agent must be injected. In the worst case, the foam product contains gas pockets and can not be sold.

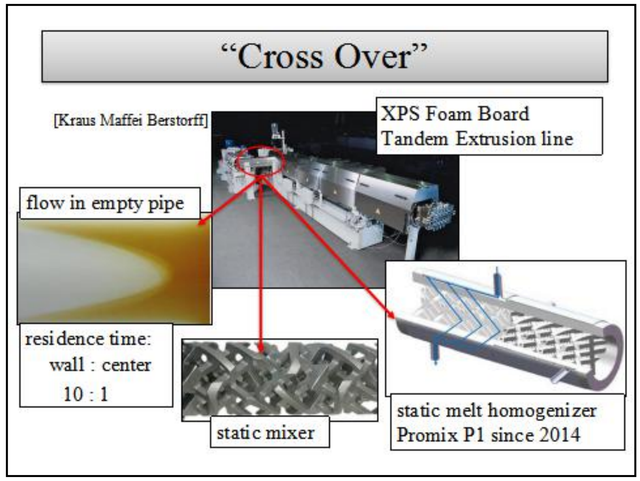


Figure 2: Options for the connection pipe

If pressure drop is not critical, mixers can be used to avoid de-mixing. As the mixing effect is lost about 1 L/D after the last mixer, the whole pipe should be fully equipped with mixers. Due to the shear stress, mixers are increasing the melt temperature, again resulting in negative stress that just should have been avoided by using the mixer - if the distance is not too long, mixers are always better than an empty pipe.

To avoid the melt temperature increase, the use of static coolers is an option - not replacing the cooling extruder but the empty pipe. Static coolers on the other hand are bad material mixers, so that a static cooler should be followed by a mixer. In 2014 Promix has launched the "melt homogenizer P1", combining a mixer with temperature control and as such avoided all negative effects of residence time distribution. Replacing a 2m long melt pipe with the P1, the flame retardant consumption (EU) was dropped by 50%!

Unluckily, about 90% of all insulation board tandem foam extrusion lines have "open" cooling screws. These "open" screws are pressure consuming screws and as a result, pressure drop is a significant problem. As both mixers and melt homogenizers are pressure consuming, they can not or only limited be used in these machines. Adding a melt pump increases shear stress that has again similar negative stress effects and is therefore not the right solution (besides cost, maintenance and leakage problems).

The "Foam MRS" device

To overcome this problem, a new solution was developed. In 2007 the company Gneuss has developed a recycling extruder, that e.g. can transfer any kind of PET regrind into FDA approved sheets of pellets on 100% regrind. This extruder is a single screw extruder with a special part in the center, the "MRS" unit: for a short section, the diameter of the single screw is increased. In this part, small screws / spindles are counter rotating inside the bigger screw. The small spindles are hold inside the housing, so that single extruder gear boxes and motors can be used, reducing significantly the cost of the extruder compared with planetary, multi or twin screw extruders, that need special gear box designs.

In this section, vacuum is applied to take out the volatile contamination of the melt. Due to this special design, the MRS is producing a surface exchange area, that is about 40 times bigger compared with twin screws and as such guarantees to take out 100% contamination.

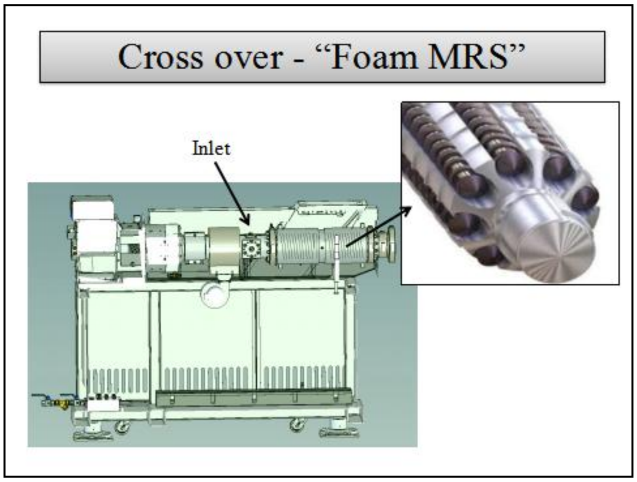


Figure 3: “Foam MRS Concept”

For foam extrusion, only the heart, the MRS part was used. In the “foam MRS” the de-gassing function was transferred into a mixing function with conveying potential, minimizing residence time distribution and overcoming the pressure limitations.

The “foam MRS” is fed with melt from the primary extruder - it does not have melting capabilities. As such the unit is short and can be retrofitted into existing machines without or only slightly moving any equipment. So the “foam MRS” is an add-on unit, that cannot stand alone.

In 2015 a XPS tandem foam line was retrofitted with a “foam MRS”, replacing the cross over pipe between the 2 extruders. Most primary extruders are put on wheels so that they can slide backwards and forwards 30 to 50 cm. This was unluckily not the case here. On top due to production pressure the request was to shorten any down time and return to the original situation within a few hours in case of failure. So the “foam MRS” was in this case even build around a platform.

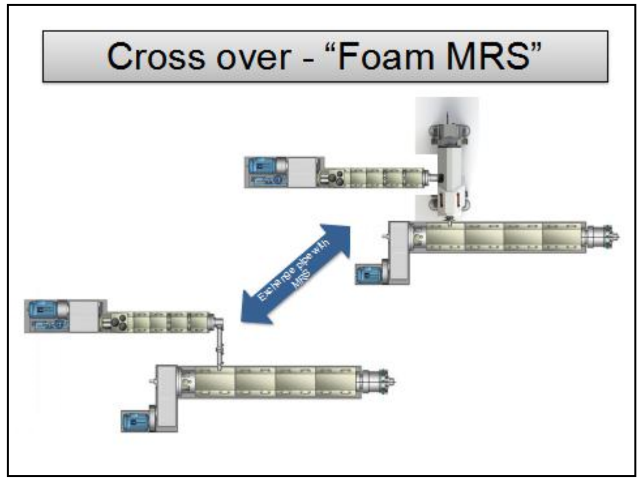


Figure 4: Foam MRS for retrofit

The speed of the center screw can be increased up to 50 rpm. At that speed, the small spindles are running on approx. 200 rpm. By changing the speed, the pressure at the “foam MRS” exit can be varied. Regular exit / inlet pressure into the secondary extruder was on the old set up about 150 bar.

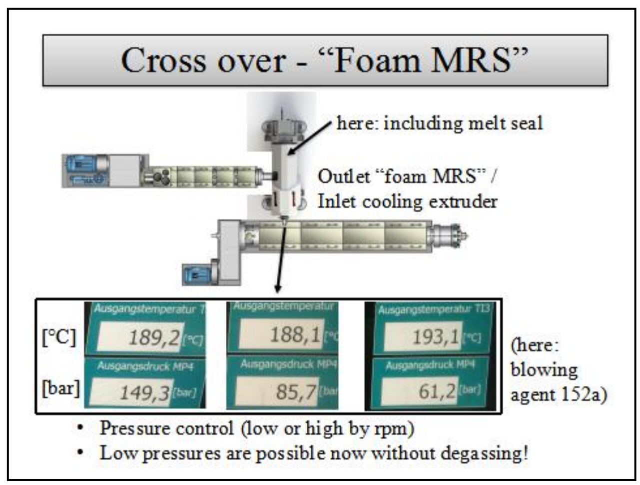
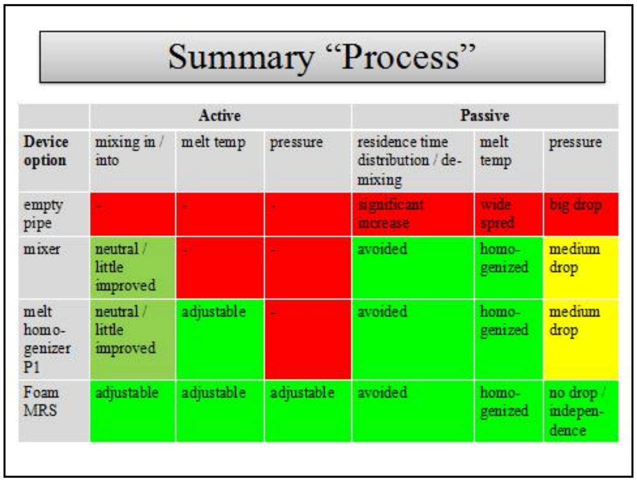


Figure 5: Process pressure independence

By screw speed, pressures could be lowered down to 60 bar. As the secondary extruder did contain a melt pump at the end, the die pressure could be kept high enough for foaming. It was found out, that even at 60 bar good foam was achieved! The pressure was independent from the melt temperature, which was started at about 200°C. The melt was in production successfully lowered below 190°C in the MRS to avoid the degradation of the flame retardant.

Comparison of technology

So with the foam MRS a device was developed that allows a precise residence time & melt temperature distribution as well as pressure control and as such overcomes the limitations of the alternative technologies.



Summary "Process"

Device option	Active: mixing in / into	Active: melt temp	Active: pressure	Passive: residence time distribution / de-mixing	Passive: melt temp	Passive: pressure
empty pipe	-	-	-	significant increase	wide spred	big drop
mixer	neutral / little improved	-	-	avoided	homo-genized	medium drop
melt homo-genizer P1	neutral / little improved	adjustable	-	avoided	homo-genized	medium drop
Foam MRS	adjustable	adjustable	adjustable	avoided	homo-genized	no drop / independence

Figure 6: Comparison of machinery options

Important to explain more in detail at this point is the word "mixing".

Explanation of "Mixing"

The word "mixing" implies an active function. This is not correct for foam extrusion! "Mixing" as active function is given only when the blowing agent is injected and dispersed into the melt - so being "mixed in / into" in the primary extruder. Once the blowing agent is inside the melt it must be kept fine dispersed in it. Assuming, it was "mixed in", from now the reversed effect, the "de-mixing", must be avoided. So behind the primary extruder, "mixing" is now getting the passive function "de-mixing". To avoid further complications, the melt temperature is not "mixed" by static mixers, but "homogenized" by them.

Homogeneous mixing

Working with the "foam MRS", interesting results were found. Foam boards were produced without using nucleation at all! As R152 was used as blowing agent, that is not self-nucleating in PS, the result only allows one conclusion: the "foam MRS" is now enabling a homogeneous mixing, as otherwise no regular foam structure could have been made! This on the other hand leads to the understanding that the mixing of blowing agents into the melt before was only heterogeneous - even using twin screws as primary extruders!

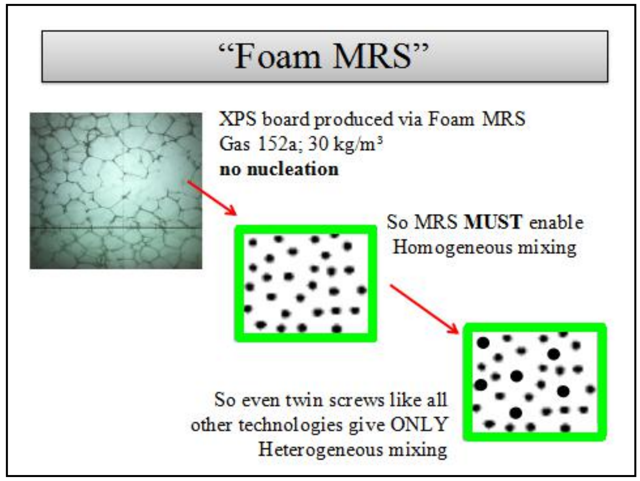


Figure 7: Mixing - the new quality showing our reality

With the potential shown of the "foam MRS", more tests have been made with blowing agents that are more difficult to be used. All of these blowing agents can be mixed easy into the melt.

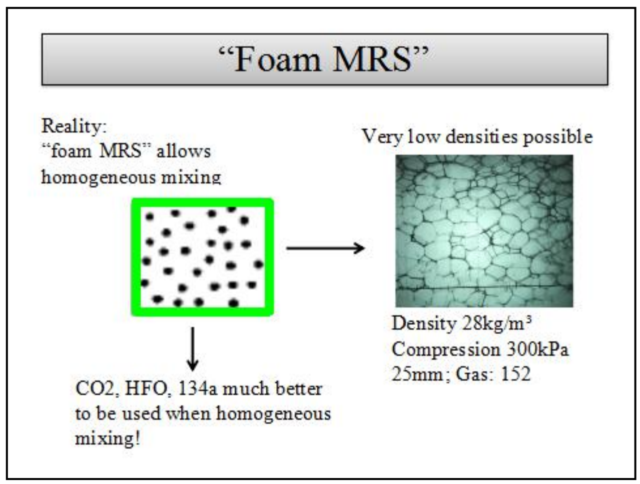


Figure 8: Results of homogeneous mixing

As well the density of the foam board could be reduced significantly, keeping all requested properties on low densities and this even on low board thicknesses!

Product benefits

Summarizing the benefits, inserting the "foam MRS" between primary extruder and cooling extruder (device), lower densities can be achieved, keeping all needed properties due to a better foam structure.

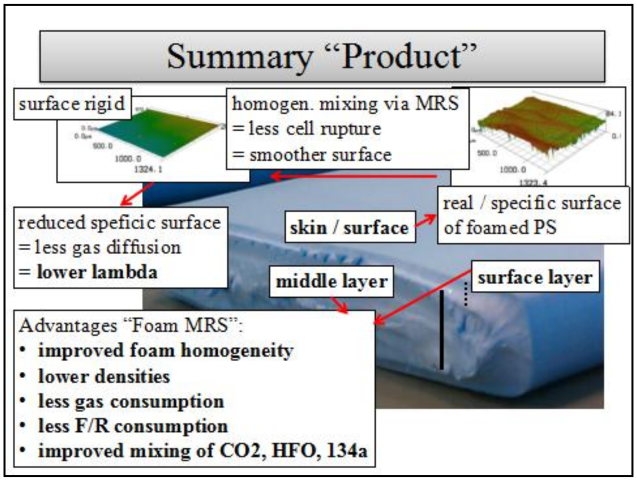


Figure 9: Product benefits

By the homogeneous mixing and improved residence time distribution, less blowing agent is needed and even HFO as on of the most difficult to use blowing agents can now be mixed easily into the melt. With controlling the melt temperature, critical additives like flame retardants can be reduced in consumption as well.

Separating the process steps

So by adding the "foam MRS" into tandem foam lines, it is possible to now separate process functions. When all mixing can be done in the MRS, the primary extruder would only need to melt the material and the solid additives. So then even regular length single screw extruders can be used with 24 to 27 L/D process length.

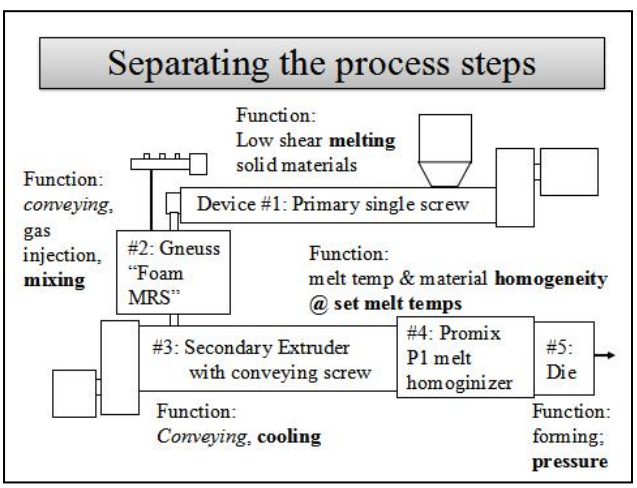


Figure 10: Advised machinery set up

The "foam MRS" can increase the pressure / reduce the pressure need for the following sections, so that a Promix P1 melt homogenizer can be added after the cooling extruder even if pressure consuming "open" cooling screws are used.

Nevertheless are "open" cooling screws increasing the residence time distribution and as such leading to de-mixing, which at the end will get to the bottle neck when using CO2 or other "difficult" blowing agents like R134a or HFO. So optimum is then to cool the melt in a cooling extruder, that is equipped with a conveying screw.

The Promix P1 melt homogenizer is then used to adjust the desired, homogenized melt temperature, separating the cooling step (cooling extruder) from adjusting the melt temperature.

As well the die is solely used to set the foaming pressure, if conveying screw plus Promix P1 is keeping material flow and melt temperature stable.

"Open flighted" cooling screws on the other hand are behaving different. Changing the die pressure leads to a pressure change throughout the whole extrusion line back to the position of maximum pressure build up inside the primary extruder. As a result, local residence time within the different machinery sections is changing. Changing the residence time in cooling zones leads to a change in heat transfer, resulting in a change of melt viscosity. This again is influencing the pressure drop. So the result is a non-constant process that requires permanent operator adjustments.

Conclusions

The possibility to overcome this unstable, swinging system are presented in the paper. Even not having a conveying cooling screw, adding a "foam MRS" into the system allows the use of a P1 and as such enabling now much better process control.

Outlook

At present, the European regional developing fund (EFRE) and the German federal state Northrhine Westphalia (NRW) are funding a research project (OP EFRE "Schaum MRS Reaktor") to further develop the "foam MRS" into a reactor. If residence time can be precisely defined, chemical reactions can be controlled. One example is the chain extension process that is needed for PET foam extrusion, where IV ~ 1.0 is desired. The bigger the machine, the bigger is the residence time window and the more uncontrolled the extension process takes place. Negative example is the presentation of a PLA foam line on a conference in Europe in 2015, where a molecular weight increase by factor eight (!) was pretended to be found on a 800kg/hr production line - in reality this was a "cross-linking" of PLA chains by uncontrolled chain extension. With the control of the residence time distribution, chemical reactions can be controlled and such problems can be avoided, opening up the foaming technology for new applications.

Vision

A regular length single screw extruder with batch gravimetric dosing station plus “foam MRS” is an alternative in terms of costs and functionality to a twin screw extruder with loss-in-weight dosing stations! So there might be in the future an alternative for twin screw extruders for compounding functions!