



Possibilities of autoclave LDPE process

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<p>Sammandrag:</p> <p>Detta arbete skrevs för att finna vilka olika polyeten plastvarianter kan en redan byggd autoklav producera. Mer specifikt söks hela möjliga produktfönstret av två olika reaktorer. Dessa produktfönster presenteras på en densitet-MFR graf som en area som kan produceras. Dessa produktfönster används som hjälpmedel för att hitta nya och gamla produkter som skulle öka på vinsten. De nya produkterna som hittades presenteras och vinsten räknas ut genom att jämföra den nya produktens vinst emot sämsta produktens vinst. Arbetet föreslår hur man skall göra de nya produkterna och hur de faller i produktionscykeln. Arbetet jämför vilka vinster är värda att agera på och diskuterar även framtiden av fabriken.</p>	
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<p>Abstract:</p> <p>This thesis was written to find what different polyethylene plastic variants can be produced in an already built LDPE autoclave. More specifically, the whole process window of the plant and from there the different product mix. These product mixes are presented on a density-MFR graph as an area that can be produced. The product windows are used as a help when looking for new and improved products that would improve the plant profits. The new products that were found are presented and the profits are calculated by comparing the possible profit of the new product with the product that has the smallest sales margin. The thesis recommends how to produce the new products by looking at the reactor specifications and how the new products fit the product cycle of the plant. The thesis compares which profits are worth acting upon and discusses how the future of the plant might look.</p>	
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1 INTRODUCTION

1.1 Background

Purpose of this thesis is to find what kind of different low-density polyethylene variations can be made at the LDPE plant in Borealis, Kilpilahti, Porvoo. The company is not satisfied with the profitability of B-unit, which is one of the two units at LDPE. First this thesis focuses on finding the process design limits, which are the combined limits of said units' compressors, reactor, extruder, cutter and product conveyer. These limits in turn decide the product mix is, which is one of the two objectives this thesis strives to find. Secondly this thesis strives to find how to increase the profits of B-unit while using the product mix as a resource.

Finding the product mix is crucial for the business aspect of the company, this way the company can easily show to customers what it can offer and this way increase profitability. It is also desired to find what new products would yield biggest profits compared to the average profit of existing coating- and film products. Finding new possible products revolve around discussing the possibilities with employees of Borealis and studying the product mix history.

1.2 Objectives

- Graph of both units' actual production window on an MFR – density table, along with explanations of why these points are possible.
- Proposals of the next important test runs, with arguments of why they would be profitable considering process capability, sales and sales margin.
- Preliminary reactor specifications for possible products and how they fit the product cycle.

1.3 Methods of study

- Studying plant manuals and old reports about how LDPE is made.
- Studying reports of old test runs made at the plant.
- Discussions with current plant engineers and old ones.
- Collaboration with different company departments.
- Reviewing plant datasheets and extrapolating data from them.

2 LITERATURE REVIEW

The plastic made at Porvoo, Borealis, LDPE-Plant is low-density polyethylene (LDPE). The process has multiple steps on how the ethylene gas is polymerized using an autoclave reactor. These steps include raising the gas pressure in three steps, cooling the gas, gas feeding, reaction, separation of gas and mass, extruding, cooling and cutting granulates into drying and storing the product. The reaction itself is explained step-by-step later. (Polymer structure and additives - Part 1, 1973)

Making polyethylene plastic can be simplified by looking at it as a one reaction. The process has several inputs these inputs decide during the reaction what is the output, which means what type of LDPE we get.

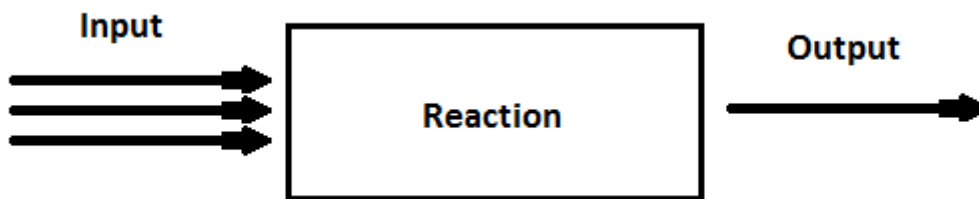


Figure 1. Simplified approach of how PE is made

The current output of LDPE is at its maximum, so if it is desired to increase the sales and monetary income, the output, also known as different grades, that sell for lowest value has to be exchanged to one that has a higher sales value.

2.1 Autoclave LDPE process

2.1.1 Ethylene pressure increase

The gas fed into the process comes from cracker as 15 bar gas. Ethylene pressure is increased in three steps to reach desired reaction pressure. Every time the pressure is increased, the temperature increases thus, cooling is needed after every increase. The first step is to feed the source ethylene into booster compressor. There the pressure is compressed from 15 to 40 bars and cooled down afterwards. The 40 bar gas is then fed to the primary compressor and pressure is increased to 250 bars. The secondary compressor is the most critical one since it converts the pressure from 250 to 2000 bars. After the secondary compressor and the cooling, the gas is then fed into the reactor along with reaction initiators. (Kulmala p.1-2)

2.1.2 Ethylene circulation

During the reaction, about 20% of the gas fed into the reactor polymerizes and the rest is separated. After the reaction the gas that did not polymerize is fed back into the process. Immediately after the reaction the product and any non-polymer compounds are separated in two stages. The pressure is also lowered in these stages. The first stage is high pressure separator. From the HPS, the gas mixture is cooled down and the gas is separated from the blend and fed back into the secondary compressor. This cycle is called recycle gas. At the second stage, the low pressure separator, the remaining gas is separated along with remains of initiators from the polymer. From the LPS the gas cycles into the so called Flash gas circulation. In the Flash gas circulation the gas is cooled down, cleaned from solvents, compressor oils and wax. These contaminants are separated into a slop system and then the gas is pressurized back to 40 bars and fed back to the primary compressor. Some amount of gas is recycled back to cracker in order to keep process gas clean from any inert components. (Kulmala p.1-13)

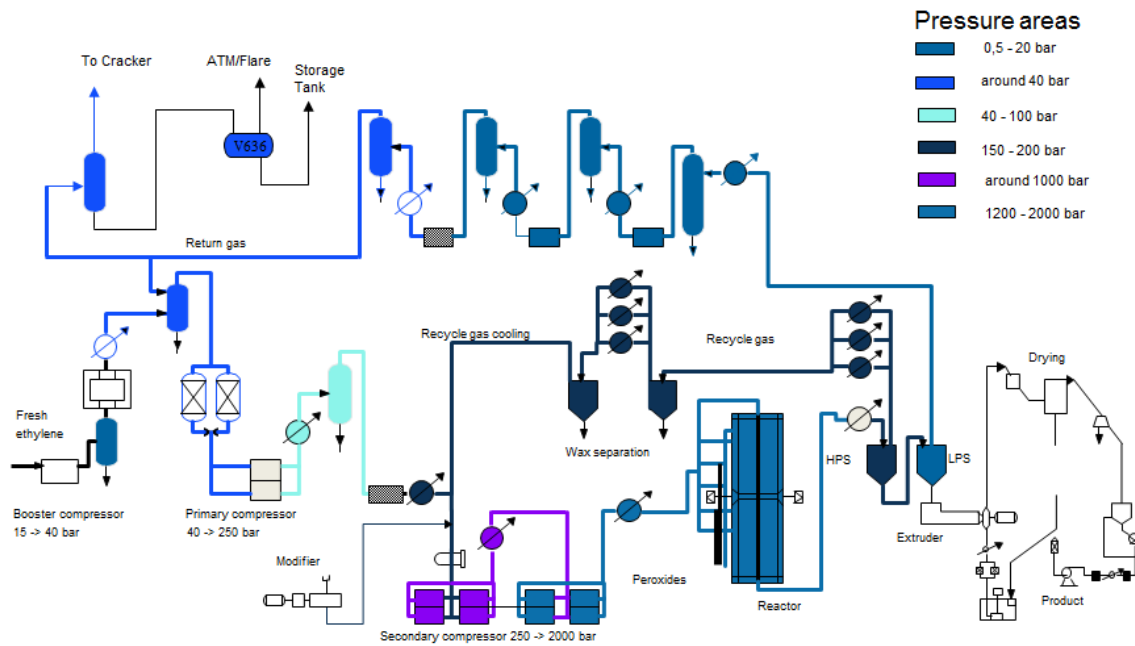


Figure 2. LDPE gas circulation and process picture

2.1.3 Extrusion and post-reaction

Once the polymer mass is separated from the gas in LPS, it is then fed into an extruder. This extruder then pushes the mass through a die and after the die the polymer is immediately cooled down and cut into granulates. The cooling happens by circulating water in the cutting chamber and with this water, granulates are moved to drying. While drying, granulates are weighted and this way the production rate is measured. After drying, granulates are conveyed with air to large silos for storing. Once in the silos, granulates still exert some ethylene gas, thus ventilation is needed for 12 hours to remove any risk of the gas forming a flammable and explosive atmosphere in the silo. (Kulmala p.14-15)

2.1.4 Reaction

Ethylene reacts with free radicals creating long polyethylene chains. These long chains in their turn react again creating long and short chain branches. (Polyethylene Reaction and Kinetics p.1.3.1-1)

2.1.4.1 Polyethylene

Ethylene that has been compressed to high pressure is fed into the reactor along with initiators. The used initiators are organic peroxides that decompose because of heat, creating radicals. Free radicals react quickly with ethylene molecules creating even longer radical chains. These chains then combine with each other creating specified long and short chains. Controlling how they react with each other is crucial for the products properties. (Kulmala p.8)

Ehrlich and Mortimer (1970) proposed the following kinetic model for the free-radical polymerization of ethylene.

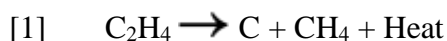
- Initiation
- Propagation
- Termination by combination
- Termination by disproportionation
- Transfer to monomer
- Transfer to solvent
- Intermolecular radical transfer
- Transfer to polymer
- β -Scission of secondary radicals
- β -Scission of tertiary radicals

All of these steps happen at the same time in the reactor.

Initially the peroxide decomposes because of heat creating two highly reactive radicals. These radicals start to react with the ethylene molecules building long chains. The chains then can, depending on the reactor conditions, join in with other chains building up a complex polymer. The chain ends when polymer end transfers to monomer. (Kulmala p.8)

2.1.4.2 Decomposition

If the reactor temperatures increase uncontrolled, the ethylene may start to decompose. Decomposition of ethylene happens in high pressures and high temperature. Borealis considers that decomposition is extremely probable after 310 °C is reached inside the reactor. When ethylene decomposes it becomes methane, hydrogen and coal. The reactions are presented below as reaction [1] and [2]. This is a high exothermic reaction and is impossible to control and hard to stop. The autoclave plants have for this reason safety mechanics to precautionarily stop the decomposition reaction. For example the automatic process control will sound alarms if temperatures rise above given thresholds. If a reaction runaway happens, the plant has rupture discs to relieve pressure quickly. (Polyethylene Reaction and Kinetics p.2.2.2)



Reactions presenting decomposition of ethylene.

2.1.4.3 Initiators

Different initiators are used in the reaction. The initiators used are decided by what grade is made and what are the specific temperatures required for the grade, which is important since temperature and pressure determine the properties of the polymer. Borealis LDPE reactors use different peroxides as initiators. They all have different temperature values where they begin to decompose. This way the reactor temperature profile can be controlled and this makes it possible to have different profiles thus different product properties. (Polyethylene Reaction and Kinetics p.2.1)

2.2 Polymer product properties

Different factors during synthesis of polymer affect the product properties. Depending of where the product will be used, different factors are tweaked to gain desired properties. All properties cannot be obtained and compromises often have to be made. (Polymer structure and additives - Part 2, 1973)

Factors that affect the polymer product are

- Molecular weight (MWD)
- Degree of short-chain branching (SCB)
- The distribution of SCB
- Degree of long-chain branching (LCB)
- The distribution of LCB
- Copolymer content
- Distribution of copolymer

Controlling the process means to control these properties.

- Temperature
- Pressure
- Feed gas temperature
- Modifier (Co-monomer)

By increasing the temperature in the reactor ethylene creates a higher degree of Short Chain Branching and Long Chain Branching. This results in a lower molecular weight. Increasing the pressure yields higher molecular weight and a lower degree of SCB and LCB. This means that temperature and pressure work inverted. Controlling the pressure and temperature to get the desired product is for this reason sensitive because increasing temperature also increases the pressure. (Polymer structure and additives - Part 2, 1973)

When the feed gas temperature is lowered the concentration of the polymer increases, this in turn increases the LCB. Adding a different modifier, for example propane, lowers the molecular weight since it shortens the length of polymer. The modifier only joins in the reaction but is never included in the final polymer. (Polymer structure and additives - Part 2, 1973)

2.2.1 Molecular weight distribution

When controlling the process the average molecule size is determined by controlling the pressure and temperature. Molecular weight distribution is the distributed sizes of molecules around this average. The amounts of long and short chains determine the average weight distribution of the molecules. Increase in the level of long chain branching results in broadening the MWD. The narrower MWD is, the more there are same length long chains. These properties are desired in specific applications of plastics. (Polymer structure and additives - Part 2, 1973)

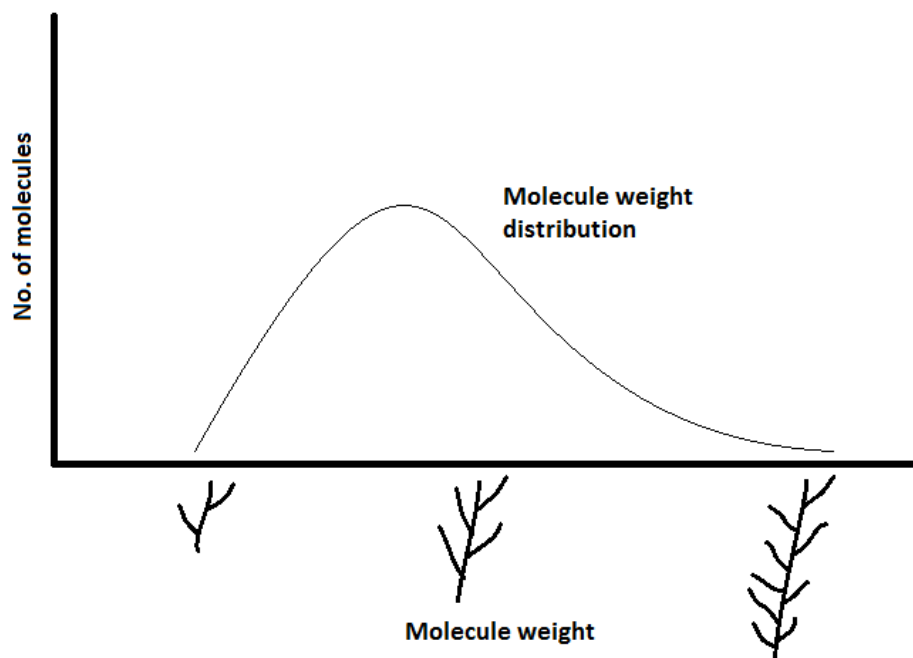


Figure 3. Picture representing MWD curve

There are different techniques to lower the degree of LCB. One of them is called two-phase reaction. In a two-phase reaction the degree of polymer is different in lower part of the reactor compared to the higher part. Two-phase happens when the temperature and pressure is relatively low. At the higher stages of the reactor these conditions are met. The idea behind this is to control the amount of long chain branching. The ethylene compressed in the reactor starts to form long chain branches, but at some point, the molecule

can no longer grow and will pass to a so called polymer rich phase. In this phase the concentration of polymer is much higher which means that all subsequent long chain branching will be shorter than in the ethylene rich phase. The rate of growth decreases substantially leading to a narrow MWD. Since the low content of polymer in the ethylene phase, the initial growth of long chains is more drastic compared to normal one-phase conditions. Meaning that the average molecular weight gained this way is much higher than in polymer obtained by one-phase condition. (Polyethylene Reaction and Kinetics p.3.3)

2.2.2 SCB (Short Chain Branching)

Short chain branching is the cause of intramolecular transfer. The amount of short chain branching in a polymer molecule affects the density, thus tear strength. Having a higher reaction temperature causes more intramolecular and intermolecular transfer leading to more long- and short chain branching. (Polymer structure and additives - Part 2, 1973)

2.2.3 LCB (Long Chain Branching)

What mostly dictates the desired properties is the amount of long chain branching. High levels of LCB aid in impact strength, environment resistance and neck-in whereas low levels of LCB makes the polymer's optical properties, drawdown and tear strength better. As said before, increasing reaction temperature increases intermolecular transfer, increasing the degree of LCB. Feed gas temperature is commonly used to increase LCB when it is not desired to increase SCB since this only affects the degree of LCB. (Polymer structure and additives - Part 2, 1973)

2.2.4 MFR (Melt Flow Rate)

Melt flow rate is calculated by how much molten plastic flows in a certain amount of time. The MFR-testing machine used, is single barrel that has a standardized weight on its piston. The piston then pushes the molten polymer and how much it has pushed out is

calculated. The usual test time is 5 minutes. (Crawford p.373) At Borealis the test is made according to ISO 1133. (Personal conversation, 13.1.2015)

The MFR is one of the critical characteristics of LDPE. It is one of the properties that is monitored when making the polymer and it also is specified by the customer to meet their needs. (Polymer structure and additives - Part 2, 1973)

MFR is one of the limiting factors for output that the LDPE process has, because the extruders are designed for a specific MFR range. Having a too small MFR, meaning that the polymer more viscous, is a possible cause of the extruder interlocking since it does not have enough power to move the molten polymer forward to the die. Having a too high MRF, when the plastic has a low viscosity, will cause the cutting to fail. The water cannot cool the plastic enough so that the cutter can get smooth separate granulates. This leads to clumping of the polymer granulates. This is why different designs of extruders exist, so that different plastic can be extruded and cut, depending on demand. (Personal conversation, 1.10.2014)

2.2.5 Density

The density range where LDPE generally is considered to belong to is $918 - 935 \text{ kg/m}^3$. Since the polymer has such a low density the impact strength is high. This also makes the polymer resistant to breaking from environmental conditions, such as cold weather.

Density is mainly controlled by the average degree of short chain branching. Having high amounts of SCB will lead to a lower density making the polymer more resilient with aspects on shear and tear. (Polymer structure and additives - Part 2, 1973)

At Borealis the testing of density is made according to ISO 1183. (Personal conversation, 13.1.2015)

2.2.6 Current product window

As explained before, these properties are the properties of the output shown in Figure 1. The output is the different plastics made, and the different plastics made are controlled

by the inputs. The current different outputs for B-unit and C-unit are represented in Figure 4 and Figure 5 respectively.

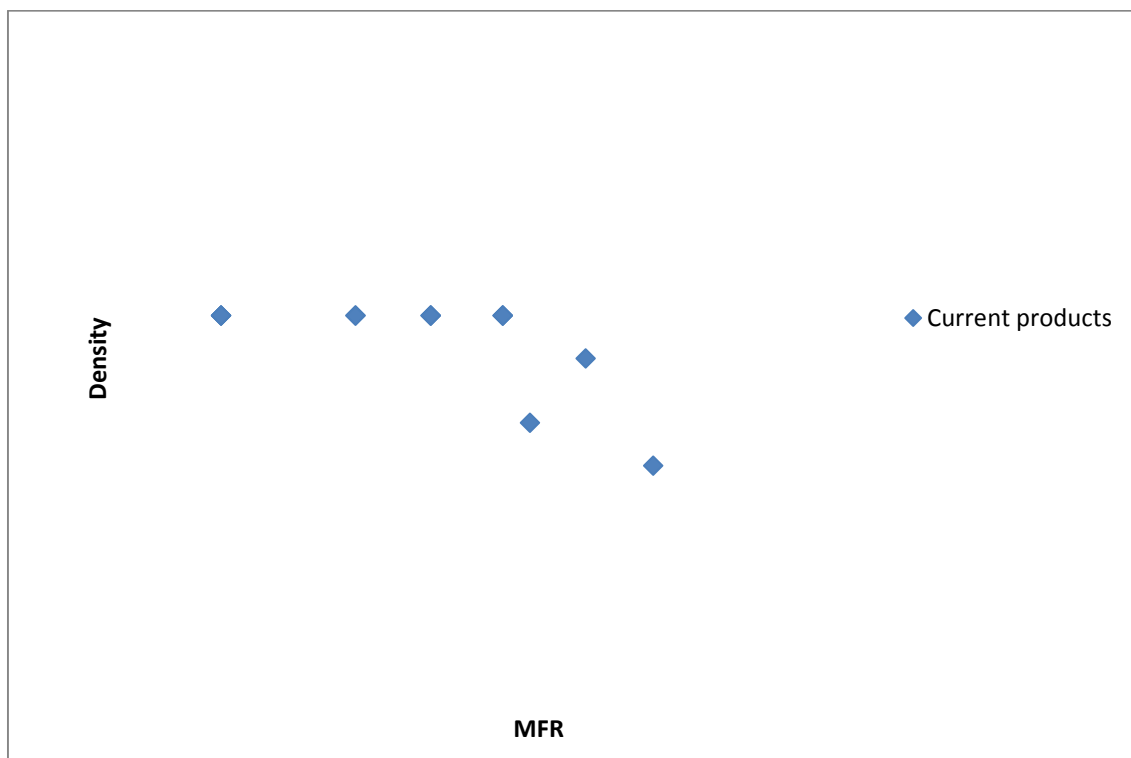


Figure 4. Current product window for B-unit (LDPE tuotteet 2011, J.Runsala)

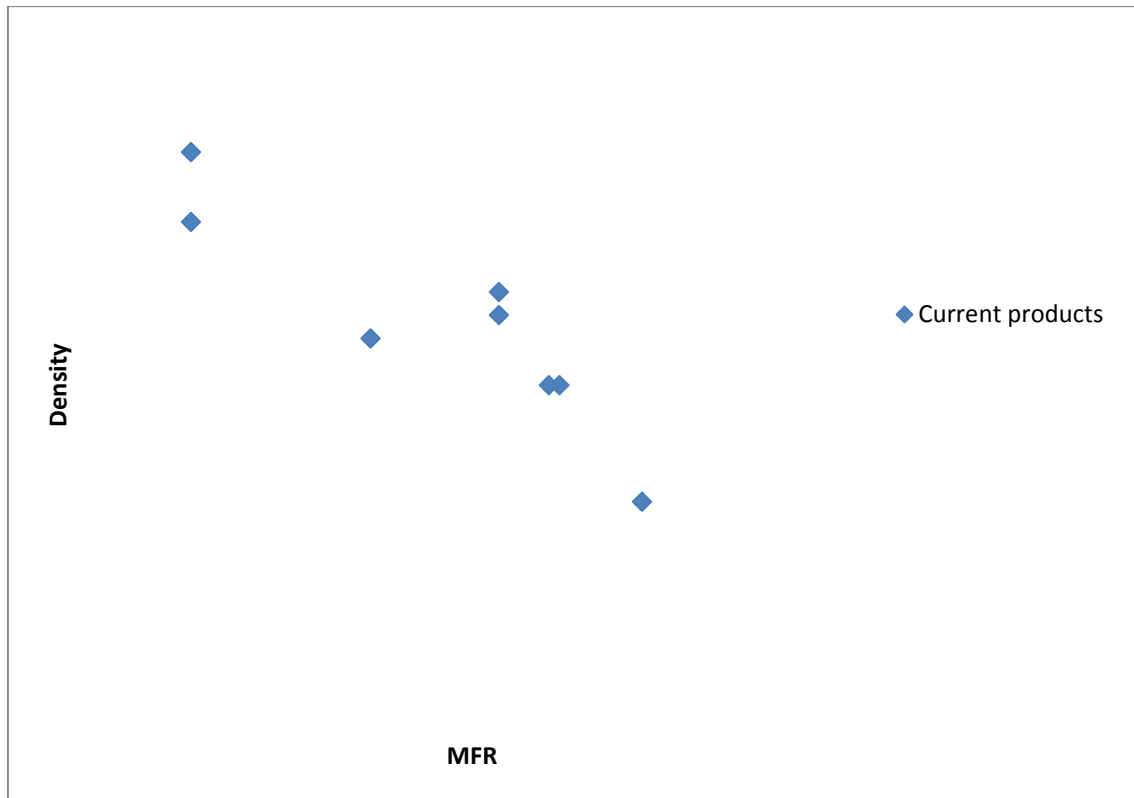


Figure 5. Current product window for C-unit (LDPE tuotteet 2011, J. Runsala)

Every dot is a product that is currently made at Borealis LDPE. The values shown are measured by the Porvoo Borealis Laboratory. The density measurements are made from small pucks of PE. The flaps of PE are first prepared by a Collin P300 P/M press that squeezes all air out and melts the plastic to fit a flap mold. Then a press cuts pucks out from the flaps and these pucks are measured. The machine that measures the density is a Mettler-Toledo machine and the density is measured according to ISO 1183 standard. (Personal conversation, 13.1.2015)

The MFR values are measured using a Göttfert MI-3 MFR measuring machine and are done as described in chapter 2.2.4.

Figure 4 and Figure 5 represent the current product window of LDPE. This window is desired to be updated on what both units are able to produce today. From these and new updated points it is desired find those grades that have the best sales margin. Then these grades are to be compared to the least selling grade seen in Table 2.

2.2.7 Desired product properties

(Polymer structure and additives - Part 2, 1973)

There are many desired properties to a product but the most commonly ones for LDPE are good optical properties, high impact strength, tear strength, heat sealability, draw-down, neck-in and toughness.

Optical properties, which refer to the haze and gloss, are extremely important to all film-grade polymer resins. The haze and gloss are exclusively controlled by the degree of LCB. It is desired to have a low level of LCB when making film-grade resins that require good optical properties.

Impact strength is better the higher MFR is, or the lower viscosity is. In the case of resins having the same MFR, the one with higher degree of LCB and narrower MWD has the better impact strength.

Resin melting temperature is controlled by the degree of SCB. This means that making a seal at a low temperature means that the resin needs to have a high amount of SCB. But if it is required that the seal is strong and not too sensitive for heat the resin needs to have a wide heat sealing range, thus a broad SCB distribution and a low degree of LCB. LCB causes the resin to have a weak seal since there is poor molecular intermingling.

Good drawdown is desired when making blown films. Good drawdown happens when the product has low levels of LCB and a broad SCB distribution. When making coating-grade resins, the SCB distribution is neglected because the operation takes place once polymer is melt. In these cases the drawdown is improved by minimizing the levels of LCB.

Good neck-in is the same as low neck-in and it is a property desired in coating-grade resins. This property is characterized by high levels of LCB and a very broad MWD.

Having a tough resin means that the resin has a good balance of impact strength, tear strength and elongation. This means that the resin needs to have a high amount of LCB, a high amount of SCB and a broad degree of SCB that gives the resin a low density.

2.3 Specific product applications

The applications in which the desired product properties are used are high quality film resins, garment film resins, liner-grade resins, shrink-wrap resins, heavy duty bag resins, cable coating resins, extrusion coating resins, cast film resins. (Polymer structure and additives - Part 2, 1973)

A high quality film resin needs to have excellent optical properties, good tear strength, drawdown and heat sealability and moderate stiffness and impact strength. To make this product the levels of LCB needs to be kept down, the MWD needs to be narrow and symmetrical and SCB distribution needs to be broad. These resins are used in general film applications. (Polymer structure and additives - Part 2, 1973)

The biggest requirement for garment film resins is their drawdown ability. This is useful when producing very thin films at high speed. The resins have a MFR that aids the draw-down, and a low level of LCB and a broad distribution of SCB. The lower the density of the resin is the better is its ability to resist splitting when in production. (Polymer structure and additives - Part 2, 1973)

Shrink-wrap resins have a specific requirement of shrinking when heated. They also need to be very tough and have good sealing abilities. Structural requirements include low LCB level, high SCB level and broad SCB distribution. (Polymer structure and additives - Part 2, 1973)

When making cable coating resins, the level of LCB needs to be extremely high. The coat needs to have excellent environmental resistance which means it cannot break when stress is applied even in low temperatures. For this reason the resin needs a very broad MWD with a broad distribution of both LCB and SCB. (Polymer structure and additives - Part 2, 1973)

When making extrusion coating resins, the level of LCB is relatively high to provide some neck-in properties. It is required that the SCB distribution is narrow and the amount of SCB to be exactly what end-user requires. Low levels of SCB provide good barrier properties, but worsen the drawdown properties. Thus it is required that the levels of LCB are lowered to increase the drawdown but at the same time it worsens the neck-in. For these reasons coating resins are delicate and need to be specified for the end-user. (Polymer structure and additives - Part 2, 1973)

Since LDPE has great processing properties, it is used as a blend component for many other plastics. The blending takes place at the customer, where they mix different granulates with specific ratios to get the product they want. Borealis Porvoo does internal compounding and then sells the resins already mixed to the customer. These resins are high quality and work as they are.

The LDPE made at Borealis is also suitable for moulding. The moulding applications differ by customer, but one application is medical field. The plastics made for this field have high standards and production needs to be carefully monitored. (LE6609-PH Datasheet)

3 BOREALIS AUTOCLAVE LDPE

The two Autoclave LDPE plants at Borealis Porvoo are B-unit, that mostly makes films, and C-unit, that makes the coating, moulding and medical products. The current profitability of B-unit is not what it should be, since the films grades it produces are not profitable. Reasons for the decline of B-unit profitability are the increased amounts of products in the film-market and customer-side compounding where the customers mix their own batches of desired mixes with required properties.

B-unit is desired to get more profitable LDPE-grades so that the nonprofitable film grade is minimized. Many films made with Autoclave LDPE process lose to Tubular LDPE-films by properties, and for this reason film grade made at B-unit is non-desired and not profitable.

Borealis has a long history in Porvoo and such as, has established a foothold in the market. The films made here are sold to several places within Finland, but they are also exported overseas increasing logistics cost and decreasing profitability even further.

(Personal conversation 1.10.2014)

3.1 Currently made plastics

The following table shows the current plastics made at LDPE, and their specifications.

FA = Film grade

CA = Coating grade

MA = Moulding

LE = Medical grade

Table 1. Borealis LDPE Porvoo products (LDPE Tuotteet 2011, J.Runsala)

Line:	Grade:	MFR:	Density:
BOREALIS	FA3220		
BOREALIS	FA3221		
BOREALIS	FA3227		
BOREALIS	FA5223		
BOREALIS	FA5224		
BOREALIS	FA6220		
BOREALIS	FA6224		
BOREALIS	FA7220		
BOREALIS	FA7224		
BOREALIS	FA7229		
BOREALIS	LE1169		
BOREALIS	MA8200		
BOREALIS	CA9150-02		
BOREALIS	CA7230		
BOREALIS	CA8200		
BOREALIS	LE1120		
BOREALIS	LE6601-PH		
BOREALIS	LE6607-PH		
BOREALIS	LE6609-PH		

The following table shows the amount sold, in tons, in 2014 for each grade and the estimated sales of future years. The table also shows the average sales margin for each ton sold. This table shows, in its' essence, which products actually bring in money and which don't. Note that GRADE1 values are calculated into GRADE2 values.

Table 2. Amount made and the average sales margin of the grades (CST25092014.ppt & APSA)

Line:	Grade:	Av. €/t	2014	2015	2016	2017
BOREALIS	FA3220					
BOREALIS	FA3221					
BOREALIS	FA3227					
BOREALIS	FA5223					
BOREALIS	FA5224					
BOREALIS	FA6220					
BOREALIS	FA6224					
BOREALIS	FA7220					
BOREALIS	FA7224					
BOREALIS	FA7229					
BOREALIS	MA8200					
BOREALIS	CA9150-02					
BOREALIS	CA7230					
BOREALIS	CA8200					
BOREALIS	LE1120					
BOREALIS	LE6601-PH					
BOREALIS	LE6607-PH					
BOREALIS	LE6609-PH					

As seen in the table above, the sales volume of GRADE2 is high compared to other grades. The sales value of the product is also notably low. According to the product man-

agement division of Borealis, this grade has a problem of breaking down at higher processing temperatures. Currently it withstands about 80% °C, when it is required to hold about 100% °C. (Personal conversation, 31.10.2014)

This product is also largely used as a blend compound component, giving good properties to other plastics. This particular grade is a big chunk of B-units' production volumes, and the average profit is lowest for it. This is the product that Borealis LDPE needs to minimize and use the ethylene gas to make something that is more profitable. Later in this study I will go through what could be possible alternatives for this product.

4 RESULTS

4.1 The Possibilities of B-Unit

When looking at the possibilities of B-unit LDPE, it is required to take into consideration what the unit is designed for. This decides the unit operating window which in turn decides what grades of LDPE can be produced. What more, many opinions and experienced thoughts have to be considered since the process is delicate and does not work by switching one constant at the time. The process of finding what can be done at the unit was started by questioning the operators of the plant, and then discussing the theory with the production engineers. During the discussions, the written knowledge and factory datasheets were constantly taken into consideration. All the factors taken into consideration are the possibilities without investments. In general, there are four main concerns that are taken into account; the pressure, the temperature, the MFR and the density. (Polyethylene Reaction and Kinetics p.3.2)

Since the amount of pressure going into the reactor is dictated by the secondary compressor, it is required to look at the maximum pressure the compressor can output. This is also the maximum pressure inside the reactor. What looks to be the current maximum reactor pressure is 100% bar, shown in percentages of current limits. (Personal conversation, 12.11.2014)

The temperature is regulated with peroxides and the conversion percentage is determined by temperature, so the minimum temperature has to be decided with consideration to the resins price because lower temperatures mean lower production rate. The theoretical minimum operating temperature is about 10% °C since going lower would mean that the MFR goes so low that the plastic is too viscous to come out from the reactor. The conversion at 10% °C is already extremely low so this is not an economically viable plastic that comes out. The maximum temperature is below decomposition temperature, which is about 300 °C. (Personal conversation, 12.11.2014)

As stated before, MFR regulates how soft a plastic is. The extruder at B-units' designed to work between 1% – 100% MFR. The specialty for B-units' extruder is the side arm extruder for additive feeding. The side arm is capable of feeding 80% t/h of additives. Maximum capacity for extruder feed with the additives included is over 100% t/h. (Datasheet L-229 B)

The extruder will handle everything Borealis makes at the unit. The issue of how soft or hard plastic can be made becomes clear when inspecting the cutter. After discussing the possibilities of the cutter, it became apparent that there is currently no consistent opinion of how soft plastic can be cut. It is however known that the current capacity of the cutter is below *** MFR. This can be raised by lowering the cooling water temperature and in the past, coolers attached to the water, cooled the plastic enough so that *** MFR was possible. This is however not the current limit since the coolers have been removed. The lowest MFR is also up to discussion, but it is generally considered to be *** – ***. (Personal conversation, 1.11.2014)

The facts of what kind of output the Unit is capable to handle is shown in the table below.

	Pressure	Temperature	MFR
Minimum			
Maximum			

What output the Unit is capable of handling does not correspond to what it can make, since that is also reliant on the reactor. The reactor plays a central point in discussing what different materials can and will be made at Borealis. These values are guidelines of finding the area on a MFR-Density graph.

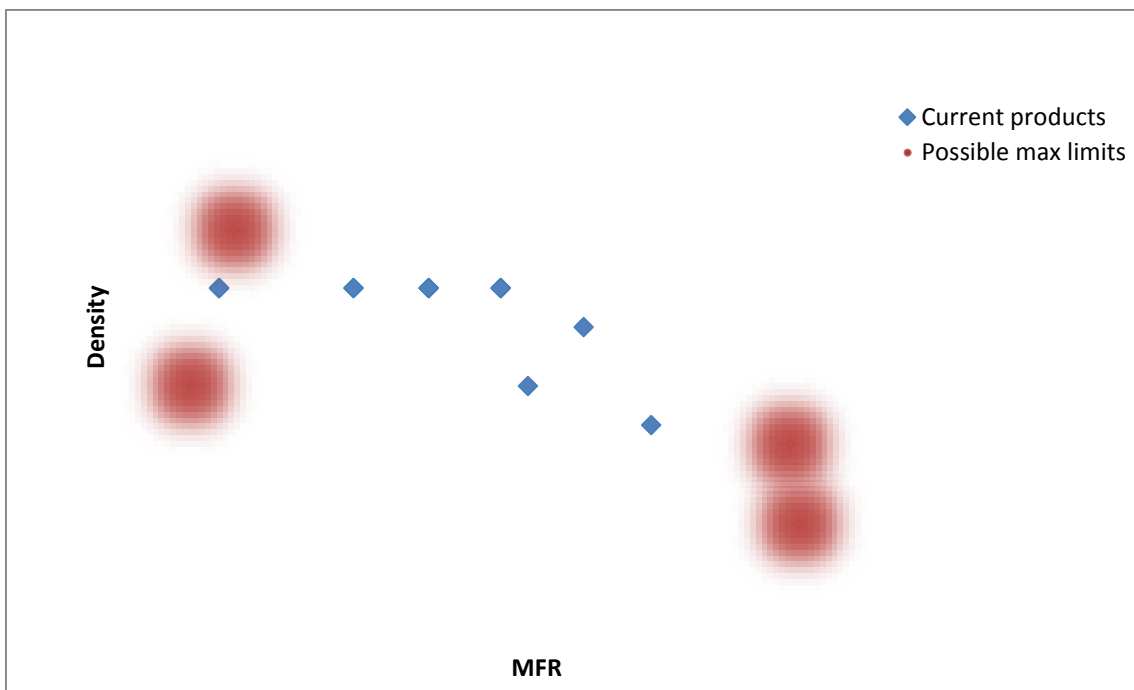


Figure 6. B-unit possible product window

Under the discussion made 12.11, it became clear that plotting an accurate MFR-Density graph is impossible since there are so many variables constantly changing while trying to change only one thing. The solution for this would be to do a test run. The discussion did spawn four areas on the graph that could be considered theoretical maximum limits. These points are theoretical in the sense that they are based on opinions of current knowledge

and experience from the past. These areas are derived from four extreme reactor conditions.

	Maximum temperature	Minimum temperature
Maximum pressure		
Minimum pressure		

Backing up the estimations of these points is the comparison of how two different grades change when going from one to another. Example:

Grade:	COAT-1	→	COAT-2	FILM-1	→	Limit Point 1
Pressure:		→			→	
Density:		→			→	

(Personal conversation 29.1)

As seen from the table, going from COAT-1 grade to COAT-2 grade, the pressure is increased by 15% bars. It is a known fact that COAT-2 has 2% higher density than COAT-1. When doing the same procedure to FILM-1, we can extrapolate that the density will increase by 0% – 5% kg when pressure is increased by 10% bars.

This same method has been used in all points, comparing the different reactor conditions and knowing what should happen once reactor pressure is increased or decreased, and what happens to MFR when changing the temperature.

4.2 The Possibilities of C-Unit

The C-unit has a larger reactor operating window when compared with B-unit. The possibilities are larger but the current need of finding new products is modest. The C-unit has a good profitability and the possible capacity is fully utilized and the product demand is high. This is well presented in Table 2.

The maximum operating pressure inside the reactor is higher than on the B-unit. The secondary compressor is designed to keep higher pressure because it has smaller pistons compared to B-unit secondary compressor. The temperatures vary slightly from B-unit because of the peroxides used. (Personal conversation, 12.11.2014)

The planned operating factors for C-unit are as follows,

	Pressure	Temperature	MFR
Minimum			
Maximum			

The cutter at C-unit is completely different from B-units' contact cutter, which is the reason why it cannot cut softer plastic than ** MFR. The cutter is a "floating" cutter which means it is held in the water by its own axle. The blades of the cutter never touch the die and it rotates between 0,05 – 0,10 mm away from the die. The cutter has a slightly higher capability of managing MFR below ** because of the small gap between extrudate and blades. (Personal conversation, 12.11.2014)

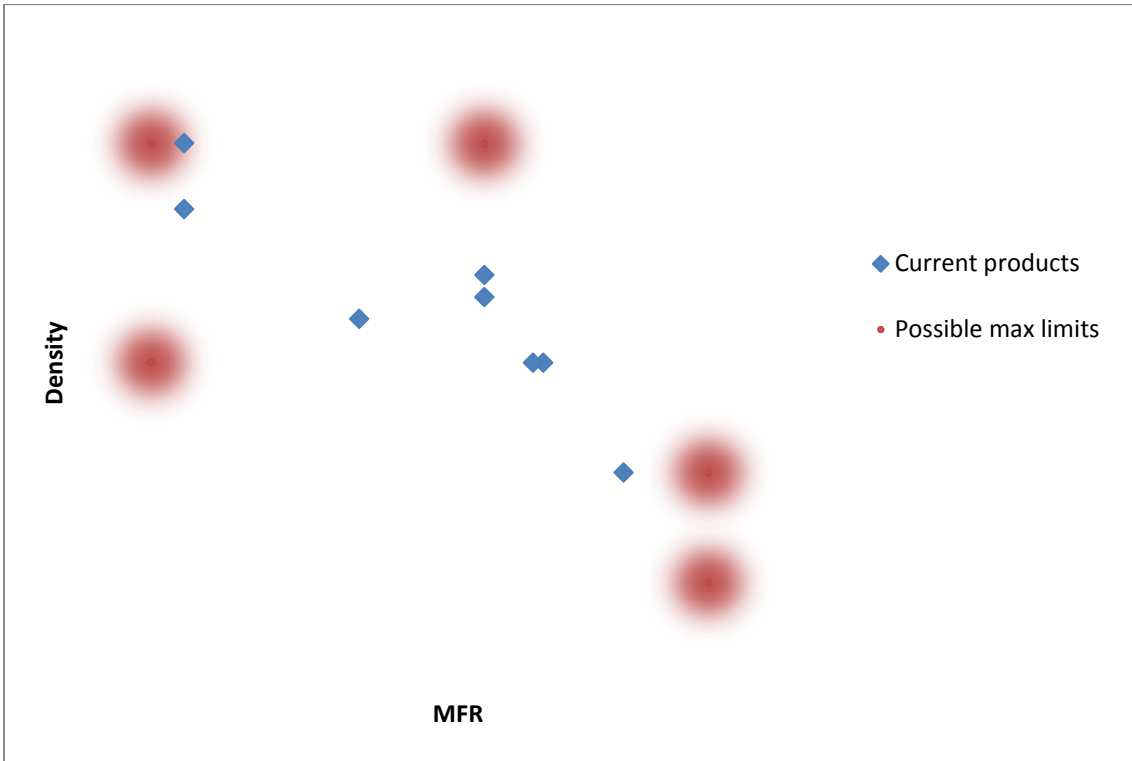


Figure 7. C-unit possible product window

As the B-unit, the C-unit's maximum properties can only be approximated as no actual data exists, as no test run of the max limits has been made. However the maximum density is higher than on the B-unit since the reactor pressure goes higher. What more, the C-unit seems to manage to keep the product density high while the MFR increases. When the reactor is at the maximum operating pressure, the temperature will be increased to make the plastic less viscous. Once MFR increases above a certain point, approximately **, the reactor pressure has to be decreased to keep the conditions below decomposition range.

	Maximum temperature	Minimum temperature
Maximum pressure		
Minimum pressure		

As said before, the only way to actually know the limits is to do a test run with these four conditions in mind. Once the exact points have been plotted, it would be possible to know the utmost areas of the units' capabilities. From there, it would be easier to derive the different products between the limits and even the reactor conditions for the products, with respect to MFR-density.

The theory behind extrapolating the maximum limit areas is the same as in chapter 5.

5 NEW APPLICATIONS

From the yearly report of the sales volumes and production capacities we can see that B-unit is making large quantities of film grades that do not sell as well as other grades would. This problem does not seem to occur on C-unit, so the focus will be on B-unit and its possibilities.

While interviewing various people of Borealis Porvoo, it was apparent that there were needs for specific LDPE plastics.

In this chapter I go through what the problematic grades are, and propose solutions for them. These solutions are developing existing grades, proposing grades that can be used in internal compounding, bringing completely new grade to the unit in focus. Each proposal goes through the same structure, presenting that it fits the product window shown in figure 6. Then I present preliminary reactor conditions of how the product could be made, how the product fits the cycle of the plant and lastly, profit calculations.

6 DISCUSSION AND CONCLUSION

Looking at the questions and comparing them to the answers found, I can tell that it's a relatively small product window that B-unit can produce on. This is of course because the B-unit is optimized for films and not coating/moulding PE. As stated during the thesis, C-unit product window is plotted but not acted upon since it makes good profits. C-unit has a bigger product window so of course it can make a greater variation of plastics.

To increase the area for B-unit, Borealis should invest into two things; the b-unit secondary compressor to reach greater densities and the water circulation cooling after cutting. These two will directly increase the density and MFR area plotted on density MFR graph.

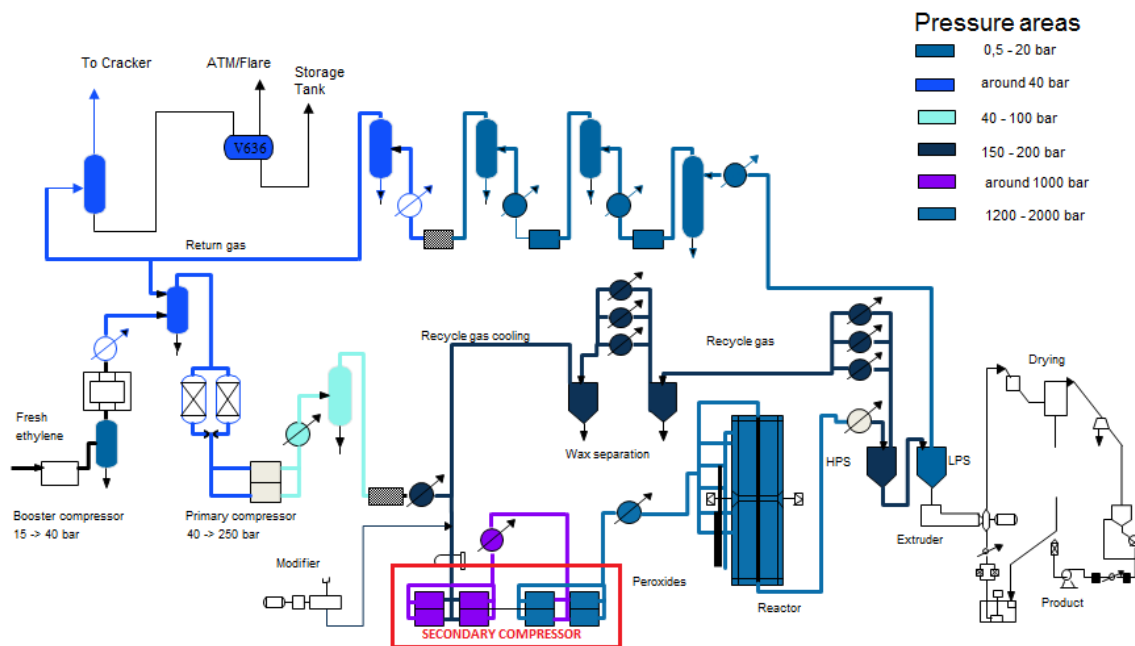


Figure 8. Process picture showing what could be changed (Secondary Compressor) to increase pressure in reactor.

Three specific cases were studied in this thesis; how developing an existing product could affect the plant profits, how internal compounding gives profits and lastly how medical grades bring larger profits to the plant compared to any other grade. The results clearly show which product should be acted upon.

Showing customers or sales representatives the MFR-density graph should help the understanding of what kind of plastics Borealis LDPE autoclave can produce. These graphs should be present during Borealis PE presentations when LDPE is mentioned.

7 SUGGESTION FOR FURTHER WORK

If it is desired to take this work further, one could pursue the following topics.

- Doing the test-runs required to find the complete product window
- Specific modifications to B-unit to get a larger MRF-density area
- Studying the new grade in depth to finalize the improved product
- Focusing on the knowledge inside the company and communicating with individuals to find different kind of applications, e.g. High density variation

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APPENDICES

LE6609-PH Datasheet

28.02.2013 Ed.1

Polyethylene Bormed™ LE6609-PH

Description

Bormed LE6609-PH is a resin intended for evaluation for use in Healthcare applications.

Bormed LE6609-PH is an additive free low density polyethylene typically used in blow moulding articles. Material is characterised with a balanced inflexibility to facilitate collapsibility of containers. Bottles and ampoules made from Bormed LE6609PH can be steam sterilised at temperatures above 110 °C. Products made from Bormed LE6609-PH can be sterilised by using ethylene oxide or radiation up to 35 kGy.

Applications

Bormed LE6609-PH has been evaluated according to different regulations and norms. Typical applications are mentioned below for Medical devices or Pharmaceutical & Diagnostic packaging. However, Borealis should be consulted for final approval to evaluate the use of Bormed LE6609-PH.

Bottles for irrigation solutions
Bottles for IV-solutions

Ampoules for injectable solutions

This grade may only be used for the applications listed in the Product Datasheet and only to the extent that the application is within the scope of the tests set out in the Statement on Compliance to Regulations on Medical Use for that grade. If an application is not listed in the Product Datasheet, the grade can be used for such application only after express written consent of the Borealis Marketing Manager, Healthcare.

Borealis prohibits the use of any healthcare grade product in an implantable device that is introduced into the human body by surgical intervention and that is intended to remain in place following surgical procedure.

Special features

No additives

Physical Properties

Property	Typical Value	Test Method
Density	930 kg/m ³	ISO 1183
Melt Flow Rate (190 °C/2,16 kg)	0,3 g/10min	ISO 1133
Flexural Modulus	330 MPa	ISO 178
Tensile Modulus (1 mm/min)	350 MPa	ISO 527-2
Tensile Stress at Yield (50 mm/min)	14 MPa	ISO 527-2
Heat Deflection Temperature	54 °C	ISO 75-2
Hardness, Shore D	53	ISO 868

Processing Techniques

Following moulding parameters should be used as guidelines:

Bormed is a trademark of Borealis group.

www.borealisgroup.com



List of personal conversations.

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31.10.2014 Auli Nummila-Pakarinen, Mikko Peltovuori, Andrei Ollikainen
1.11.2014 LDPE Shift-4
12.11.2014 Ismo Savallampi, Jussi Runsala, Janne Lassila
27.11.2014 Ruth Dammert
2.12.2014 Sanna Ronkainen, Hannu Tahvanainen
19.12.2014 Jussi Runsala, Janne Lassila
13.1.2015 Seppo Nylund
20.1.2015 Ismo Savallampi
29.1.2015 Janne Lassila
29.1.2015 Mikko Peltovuori
30.1.2015 Henrik Westerberg, Ismo Savallampi