SULZER

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DEVO™ Technology for Dissolution Recycling

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Summary

The recycling of polymers presents both a critical challenge and an opportunity to incorporate sustainability in industrial practices worldwide. Traditional mechanical recycling methods are the first choice for plastic recycling, both economically and, in some cases also, environmentally. While mechanical recycling is an excellent choice for single polymer streams with low contamination levels, it is not suitable for complex polymer products consisting of multi-material composites and complex streams. Besides, mechanical recycling inevitably results in material degradation after each recycling cycle, leading to materials downcycling. Increasing recycling content targets (30% for all plastic packaging by 2030) drives the development and adoption of advanced technologies that promise enhanced efficiency and superior quality in recycled products.

Dissolution recycling or alternatively called solvent-based recycling has captured the space between mechanical recycling and chemical recycling technologies, offering superior product purity and quality over mechanically recycled polymers while preserving polymer structure. It allows for lower energy consumption and related CO_2 footprint compared to other technologies, breaking down polymers into smaller fragments, like pyrolysis.

Sulzer Chemtech contributes to this recycling technology with its DEVO, an advanced solution designed to remove traces of solvents from recycled polymers. This whitepaper describes the principles and benefits of solvent-based recycling, then elaborates how Sulzer devo technology helps reaching the desired polymer quality and finally argues that static devolatilization is superior to extrusion-based degassing.

References

[1] https://www.oecd.org/en/topics/resource-efficiency-and-circular-economy.html
[2] United Nations Environmental Programme and Secretariat of the Basel, Rotterdam and Stockholm Conventions (2023). Chemicals in plastics: a technical report. Geneva
[3] Information from BlueWave Consulting and Grandview Research
[4] TOMRA, Polysecure
[5] Klotz et al., Science of the Total Environment 906 (2024) 167586
[6] Zhao et al. Chemosphere 209 (2018), 707-720
[7] Triebert and Hanel, www.researchoutreach.org
[8] KraussMaffei 2022; Coperion brochure on integrated devolatilization processes
[9] Kohlgrüber C.,Plastics Compounding and Polymer Processing 2022, Carl Hanser Verlag, p 362ff.
[10] Compounding part 1; PT online published 9.3.2020
[11] Wäckerlin and Nising, Macromol. Symp. 2007, 259, 17–25

1. Introduction: Why dissolution recycling?

The global production of plastics hit a staggering 400 million metric tons in 2022. Shockingly, only 55 million metric tons were recycled, a fraction of what ended up in landfills (174 million metric tons) or was mismanaged (82 million metric tons) in 2019, as per the OECD [1]. The 2023 UNEP report [2] further reveals that 56% of the plastic waste generated is dumped in landfills or dumpsites, posing a severe threat as hazardous chemicals can seep into the environment. The report provides a comprehensive overview of the hazardous substances in plastics, the risks they pose to the ecosystem and humans, and potential substitutes. It also offers valuable insights and recommendations on plastic recycling.

There are several key reasons explaining low recycling rates: (1) difficulty with collection and sorting, (2) limited amount of recycling infrastructure and technology maturity, and (3) economic viability. It is a consensus worldwide that the situation must change to achieve circularity of products and materials. The methods for plastic recycling range from physical processes, keeping the molecules mostly intact, to chemical processes, depolymerizing the molecules or even going back to basic chemicals. The method of choice depends on the polymer type, required degree of purity, and associated cost. Sulzer Chemtech is actively developing several recycling processes as we believe the answer will lie in a combination of solutions, both physical and chemical recycling.

Dissolution recycling offers a promising middle ground between mechanical recycling and chemical recycling. It is one of the few recycling technologies which keeps the polymer structure intact. Together with mechanical recycling, dissolution recycling is often ranked as physical recycling because it does not involve any chemical reactions that break down polymer chains into primary building blocks. On the other hand, Zero Waste Europe classifies dissolution recycling as a chemical recycling process because of the chemical interaction between solvents and polymers. Dissolution recycling involves the dissolution of the plastic containing additives and impurities in a solvent, which selectively dissolves the desired polymer. Unwanted additives, colorants, and contaminants are filtered out, and the desired polymer is precipitated or devolatilized.

The global dissolution plastic recycling market was estimated at $ 600 million metric tons in 2021 and projected to reach $ 1 billion by 2030, indicating increasing opportunities for dissolution recycling. Dissolution recycling is still an emerging technology; therefore, most existing plants are on a pilot and demo scale. As the technology quickly matures and the demand for recycled plastics grows, larger commercial-scale plants in the range of thousands of tons per year capacity will become viable. The plant size would depend on several factors, including feedstock availability, type of polymer, logistics, and specific regional market dynamics [3].

Currently, Europe is the leading region in promoting a circular economy due to stringent plastic waste regulations, but other regions are catching up. For an overview, see Sulzer's whitepaper - Cammerer, S., Dissolution Recycling: "Rising star on the plastic recycling horizon". It is unclear which recycling technology will be preferred for each polymer type. However, mechanical recycling is generally considered the least energy-consuming technology, which should be regarded as the first choice. Secondly, dissolution recycling could emerge as an improved mechanical recycling as it yields better polymer properties for certain plastics. Achieving economies of scale while addressing feedstock, technology, and market challenges will drive the economic viability of larger dissolution recycling facilities.

2. The process of dissolution recycling

Collecting and sorting

Depending on the consumer waste management system of a country, selected streams or a mixture of used plastics are collected and further processed. In Switzerland, PET bottles have been collected separately for many years and recycled back into bottles. Polyolefin bottles have also been collected all over Europe, and other consumer waste plastics collection has started. In Germany and Sweden all plastics are collected in the yellow bin and sorted in the recycling facilities. Currently, sorting and washing technologies are being developed, which will greatly improve the quality of the different plastic streams, simplify any further recycling steps, and massively improve the quality of recycled polymers [4].

In a recent study, Klotz et al. estimated for Switzerland that in 2040, 31% of used plastics could be chemically recycled by gasification, pyrolysis, depolymerization, and dissolution, while a further 23% would have to be gasified or sent to pyrolysis [5].

While in principle, all but thermoset polymers could be treated with dissolution treatments, the plastics for which solvent-based processes are available are currently typically PS, PP, PE, PA, PET (textile), and PVC. Especially interesting are multi-layer films, which are difficult to recycle by mechanical recycling due to the difficulty of separating them into their components and the different degradation properties.

Feed preparation and Dissolution

The core of dissolution recycling is dissolution, where a solvent or mixture of solvents selectively dissolves a specific type of polymer. The choice of solvent is crucial and is based on its ability to effectively dissolve the target polymer while leaving others intact. Polymers don't dissolve instantaneously, but the solvent needs time to diffuse into the polymer through the surface and disentangle the polymer chains. This process is easier with lower molecular weight polymers, higher temperature, and smaller size of the plastic part. Smaller solvent molecules tend to diffuse faster than larger ones. Several methods were developed to speed up dissolution, like applying microwaves or adding a small portion of a non-solvent. Ideally, the selected solvent dissolves only the target polymer, and all others not, Zhao 2018 [6] Triebert [7].

Before reaching the core step of dissolution, the feed must be further sorted and/or washed in order to remove foreign matters such as metal, inorganic and organic matters.

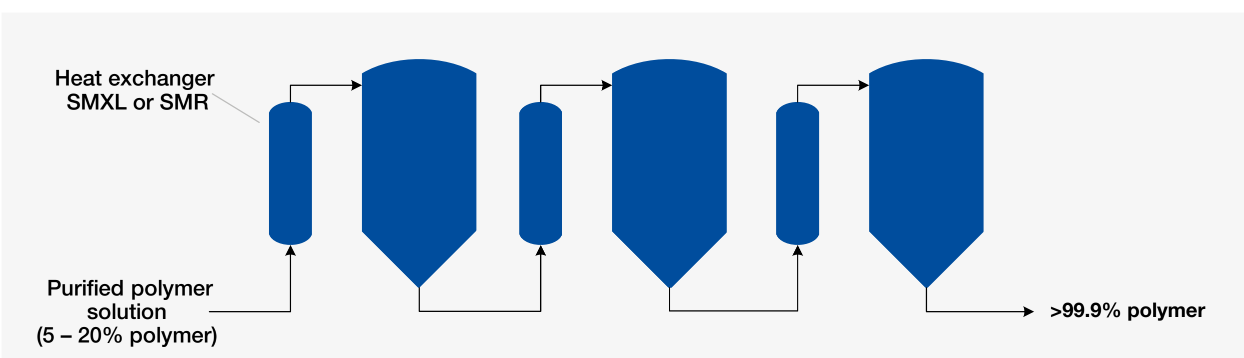
Filtration/Precipitation/Devolatilization
The next steps of dissolution recycling involve the separation of the target polymer from impurities and undissolved plastics using any suitable method, such as filtration or centrifugation. The purified solution, which still might contain unwanted additives like color, antioxidants, processing aids, and the like, is further treated with adsorbing agents or other purification methods before the target polymer is selectively precipitated with an antisolvent or by changing temperature or pressure conditions. In the final steps, typically, large amounts of solvent must be separated from the target polymer. Two applied methods, devolatilization in static and dynamic equipment, are discussed in further detail below.

Quality of recycled material and the recycling process
Removing contaminants, including additives like color, flame retardants, plasticizers, stabilizers, and others, is the solvent-based recycling goal. Especially hazardous chemicals like flame retardants are important to be extracted before reuse of the polymer. The 2023 UNEP [2] report gives an overview of such chemicals and recommendations related to recycling. Several efforts are undertaken to agree on standards for recycled plastics collection, analysis, and quality of recycled materials and products made from them or containing recycled materials. The standard UNE EN 15343:2008 is a European standard “Plastics – Recycled Plastics – Plastics recycling traceability and assessment of conformity and recycled content” that establishes requirements for traceability, characterization, and verification of recycled plastic content in plastics products. This is the first step towards a standardized framework for traceability and conformity assessment of recycled plastics across Europe. From January 1, 2024, UNE EN 15343:2008 became mandatory for certifying recycled content in plastic packaging in Spain.

Companies like RecyClass offer EU-wide certification of recyclers to show that the post-consumer plastics processed in their plant are treated according to best practices and with respect towards the environment.

3. The DEVO Technology

Sulzer’s DEVO technology streamlines polymer recycling via a multi-stage process that increases the polymer concentration from initial concentrations of 5-20 wt.% to the required residual solvent level, typically achieving > 99.9 wt.% polymer concentration. It uses Sulzer’s proprietary static mixer heat exchangers and degassing chambers with customized internals. The number of degassing stages is designed according to the need of the process and could vary.



1st stage: Pre-Concentration
The process starts with a polymer solution of 5-20 wt% concentration. The polymer solution is heated up to temperatures where the saturation pressure of the volatile becomes higher than the pressure in the flash chamber. Heat exchangers like Sulzer SMXL™ or Sulzer SMR™ are used to bring the solution to the right temperature. They are engineered for optimal thermal transfer, facilitating the rapid evaporation necessary for solvent removal while preserving polymer integrity. Since the solution’s viscosity is low in this stage, the volatile is removed rapidly by boiling. Vapor bubbles form and expand, and the volatile leaves the solution. The equipment is designed to avoid the entrainment of the polymer by the volatile gas stream. During this process, temperature is lowered due to the evaporation energy needed, and viscosity increases due to the temperature decrease and concentration increase. The now highly concentrated polymer solution leaves the vessel at the bottom and is transferred to the next stage.

2nd stage: Intermediate Concentration
In the second stage, the now thicker polymer solution undergoes further solvent extraction. The solution is heated again before entering the degassing chamber to reach the optimal conditions for removing volatiles. The concentration is precisely increased to over 90%. The system maintains tight control over thermal conditions to prevent polymer degradation, ensuring consistent quality.

3rd stage: Final Purification
The final stage employs heat exchangers (SMR) again to set the temperature of the now very viscous solution. Volatile removal is now controlled by diffusion of the volatile to the interface between molten polymer and gas phase. This process is much slower and requires time. A stripping agent may be added for enhanced performance. The effect of the stripping agent is, firstly, the reduction of the partial pressure of the volatile in the vapor phase and, hence, the equilibrium concentration in the polymer phase; secondly, it improves the foaming of the melt. By designing the optimal internals for the degassing chamber, residence time can be controlled, and polymer concentrations greater than 99.9% can be achieved. This step is critical for end-uses demanding the highest purity levels, eliminating solvent traces to meet required standards.

Upgrading and Pelletization
After the devolatilization, additives can be mixed into the polymer melt prior to pelletization to upgrade the final product. Sulzer has many years of experience providing successful upgrade solutions based on static mixers to improve product quality and profitability of customers' products and processes.

The DEVO process is Sulzer's technical contribution to the dissolution polymer recycling industry, focusing on optimized, high purity outcomes.

Solvent purification
In dissolution recycling, the purity of solvents is important to ensure the quality of the recycled polymers. Over time, solvents recovered in the DEVO sections accumulate impurities, which can compromise the whole process. Recovering and reusing organic waste solvents are essential to help minimize waste and environmental impact and save costs. The goal is to obtain a high yield and purity product with minimal expenditure. Distillation has, historically, been the most commonly used technique because of its ability to separate components from a fluid mixture at a wide range of flow rates, regardless of the initial concentration, and with high purity. Since solvent recovery may require multiple stages to be completed, engaging with an experienced partner will be key, as well as optimizing the design to deliver product quality, increased capacity, and reduced energy consumption. Sulzer Chemtech is a leading expert and solutions provider for a range of distillation technologies and has been supplying process solutions in this field since 1940. To date, more than 100'000 columns are operating with Sulzer equipment in over 500 different applications.

Our product portfolio includes a unique and complete range of the best performing, state-of-the-art column internals:

- Structured packing (like MellapakPlus™)
- Random packing
- Trays (conventional, high performance and cartridge trays
- Column internals (like distributors and collectors) Vapor-liquid and liquid-liquid phase separators (like KnitMesh™mist eliminators and Mellachevron™ vane packs).

Sulzer Chemtech offers customers either a basic engineering package including key equipment (column shells, internals, heat exchangers, and decanters) or a complete, often skid-mounted unit, including process control and start-up support services.

By incorporating Sulzer's distillation technologies into solvent-based recycling plants, not only does it extend the lifespan of the solvents, but it also significantly reduces the environmental footprint by minimizing waste and the need for fresh solvent production. This alignment with sustainability objectives further underscores the pivotal role of Sulzer's equipment in enhancing the overall efficiency and effectiveness of polymer recycling operations.

4. Comparative Analysis: DEVO Technology versus Degassing Extrusion

This chapter explains the critical advantages of DEVO technology, illustrating how it enhances the quality of the recycled polymer and delivers substantial economic and environmental benefits. The drawn comparisons elucidate why DEVO technology is an exemplary choice for industries aiming to integrate sustainable and cost-efficient practices into their polymer recycling operations.

General considerations
In all devolatilizing devices, conditions for optimum separation must be created by the liquid distribution, pressure, and temperature to ensure mass transfer of the volatile component from the liquid to the gaseous phase. High available surface, low pressure, and high temperatures favor the transfer of solvent to the gas phase. Devolatilization is always a coupled process of mass and energy transfer.

The range of viscosities covers $< 10^{-3}$ Pa·s to $> 10^{5}$ Pa·s, i.e., from low viscous liquids to high viscous polymer melts. The devices for devolatilization accordingly vary from flash evaporators, and falling-film devolatilizers to thin-film devolatilizers, falling-strand devolatilizers, and screw machines. They range from mostly static to dynamic equipment.

Mass transfer occurs in all equipment and processes when the phases are not in thermodynamic equilibrium. The maximum devolatilization level that can be reached is determined by the thermodynamic equilibrium at the process conditions. The choice of an appropriate system and the design of the devolatilizing zone depend on material properties and operating conditions, while theoretical descriptions are often unavailable. Experimental results are necessary for the design and scale-up of a devolatilization process.

In summary, while the fundamental thermodynamic principles govern the limits of devolatilization, the practical implementation relies heavily on experimental testing and data. Pilot trials are key to optimizing the equipment design and scale-up for a specific devolatilization application.

For a successful devolatilization, the following points need to be taken into account

- Temperature and pressure must be precisely controlled. Thermodynamic equilibrium determines the volatile component concentration in the polymer and the gas phase.
- Mass transfer depends on time and available surface.
- Efficient heat transfer needs to occur.
- Concentration changes result in viscosity changes and the device must be able to cope with it.
- Long residence times and high temperatures can lead to degradation in the polymer.
- The volatile component must be removed efficiently, without entrainment and condensation.

From the above, it is clear that we need to efficiently balance removing the volatile component with avoiding polymer degradation. In the process of removing volatiles from high to low concentrations, heat transfer and gas volume typically determine the design of the stages. However, at low inlet volatile concentrations, residence time becomes more important. In the low-viscosity range, mostly static equipment, like the Sulzer devo technology, is used. For the last stage, typically, two different technologies are available, allowing very different residence times: mostly static equipment, like the Sulzer strand devolatilizer, and rotating equipment, like a twin-screw degassing extruder.

Twin-screw extruders can decrease the volatiles from the 'initial 50% solvent to the higher ppm levels' [8]. Twin-screw degassing extruders can remove up to 15% volatiles per section, while single-screw extruders reach 5% removal per stage [9]. A good rule of thumb for vented machines is that each vent can bring the concentration of volatiles down by an order of magnitude [10]. With static devolatilization, levels below 50 ppm can be reached [11], and several stages can be designed one after the other, starting from polymer levels as low as 5% in the solution.

Both technologies allow the use of stripping agents like water or inert gas. It helps devolatilizing, especially in the last stage, where only a little volatile is present, by reducing the partial pressure of the gas and pushing bubble formation. A limit of devolatilization is reached when the volatiles become too large molecules or have too low vapor pressure. In these cases, temperatures would have to be chosen which are too high for the polymer to remain intact, or vacuum levels would have to be too low to be realistically used.

Enhanced Polymer Quality

Sulzer's DEVO technology sets new benchmarks for the quality of the recycled polymer, mainly due to the lower shear forces and the precise temperature control.

Static devolatilizers have the significant advantage of precise temperature control. This is achieved by bringing the polymer-solvent mixture to the desired temperature level in heat-exchangers instead of applying mechanical energy as in screw machines. If necessary, additional heat can be added by applying a loop design where part of the devolatilized stream is recycled back and mixed into the incoming stream. Pressure is set in the devolatilizing vessel, while medium to long residence times can be reached by varying the design of Sulzers proprietary devolatilizing vessel internals.

It is often reasoned that degassing extruders have the advantage of constantly renewing the surface, allowing the polymer to be devolatilized and pumped simultaneously. However, in extruders, the shear is high with high-viscous media, and the energy cannot be easily dissipated, so the temperature of the polymer increases. In degassing extruders, the degassing zone must be sealed towards upstream and downstream process sections, and this is usually achieved by back-conveying elements or neutral kneading blocks. Such sections lead to increased shear and respective energy input. With DEVO operating at approximately 90% lower shear rates than degassing extruders and sustaining operating temperatures of up to 50°C less in peak, the molecular weight loss in the process is typically strongly reduced, thus protecting the initial product properties. This is especially true for polyesters and polyamides, still it is also crucial for polyolefin polymers since it is not possible to recover molecular weight with further processing for these polymers.

Reduced Costs with DEVO Technology

Sulzer Chemtech's DEVO technology redefines cost-efficiency in dissolution polymer recycling by leveraging static equipment that significantly undercuts the operating expenses associated with degassing extrusion. This is achieved through a reduction in capital expenditures (CAPEX) and operational expenses (OPEX). On a system basis, DEVO technology, compared to degassing extrusion, can achieve lower total investment costs not only by reduced equipment cost itself but also through reduced OSBL (outside battery limits) costs. The reduction in power demand of up to 90% is the key driver here.

Unlike extruders, which run solely on electricity, DEVO technology can utilize heat from energy recovery sources like waste incineration and fuel gases, resulting in operational cost savings of 60-70% on a kWh basis. Beyond that, the maintenance costs for the DEVO system are significantly below typical degassing extruders, as the rotating equipment is limited to the gear pumps used in the polymer degassing train. The maintenance of these pumps typically requires significantly reduced efforts compared to extruder maintenance.

Proven and reliable scale-up
DEVO technology was initially developed for the traditional polymer industry and has been proven in more than 40 references with scales of up to 450 kt/a, achieving the remaining VOC level in the parts per million (ppm) range. The technology's reliability is enabled and reinforced by extensive testing facilities in Switzerland, ensuring that scale-up from small technical size to industrial capacities is seamless and predictable. Here, our customers are invited to witness the capabilities of the technology to gain the confidence needed to invest in DEVO technology.

5. Conclusion: Embracing the Future of Polymer Recycling with DEVO Technology

Solvent-based recycling presents a promising solution for achieving high-quality plastic recycling, especially for polymer streams, which are difficult to recycle mechanically. It allows for the removal of impurities, additives, and degradation products, producing a recycled material with properties comparable to virgin plastics.

Sulzer Chemtech's DEVO technology is a game-changer in this field, offering an innovative and efficient solution for solvent-based polymer recycling. This whitepaper has explored DEVO's notable cost savings and enhancements in polymer quality, showcasing it as a step beyond traditional degassing extrusion with positive economic and environmental impacts. The key features that make DEVO stand out include: DEVO's static design with no moving parts significantly lowers both initial costs and operating expenses, promising long-term profitability.

- The process ensures polymer quality through reduced thermal and mechanical stresses, suggesting new uses for recycled polymers and broadening market opportunities.
- Customization and optimization. The Sulzer team conducts extensive simulations, laboratory testing, and pilot trials to fine-tune the DEVO process for customer-specific applications.
- Complete process packages. Sulzer offers complete solutions including solvent recovery units, mixers, process guarantees and commissioning support.

Finally, the technology's scalability, backed by over 40 industrial references, demonstrates its versatility and readiness for various recycling scales. DEVO is positioned to lead the transition towards a circular plastics economy, with Sulzer Chemtech at the forefront of driving sustainable innovation in recycling technology. As the demand for high-quality recycled plastics continues to grow, driven by sustainability trends and regulatory pressures, Sulzer's DEVO technology enables the recycling industry to meet increasingly strict recycling rate targets while delivering materials that match the quality of virgin polymers.

	Advantages of Sulzer DEVO technology over degassing extruders
Investment costs	**Reduced investment costs since:** > DEVO technology significantly benefits from economy of scale. > Mainly static equipment instead of rotating equipment used. > Reduced OSBL costs through reduced electric transformer size by > 90%
Operating expenses	**Reduced operating expenses due to:** > Using traditional heat sources or waste heat instead of electricity feasible. > Reduced maintenance costs since gear pumps are the only rotating equipment.
Process advantages	> Excellent temperature and pressure control in all three stages > About 90% reduced shear stress - significantly reducing the loss of molecular weight. > Increased residence times of the polymer eliminating diffusion induced limitations in degassing extruders. > Single technology system from the whole degassing process > Easy to scale-up > Proven technology on Industrial scale
Design flexibility	Design can be fully tailored to the application in contrast to degassing extruders typically supplied in standard sizes.

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