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PE 100 large-diameter pipes in sewage treatment

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FRANK belongs for more than 40 years to the leading suppliers on the plastic pipe market. With complete polyethylene-based (PE-HD) piping systems for industry, supply of gas and water and the sewage sector, the company offers fully developed PE-HD solutions. High-density polyethylene pipes, in particular, stand out in this field from the other, “classical”, materials. The improved performance of modern multimodal pipe materials in performance class PE 100 has also made it possible to improve piping system properties and characteristics.

This article describes large-diameter spirally wound PE 100 pressure pipes from *Hostalen CRP* 100 black for new underground denitrification tanks with inside diameters ranging from DN 1000 to DN 1400 and a large range of special components for a sewage treatment plant close to the city of Ulm in the southern part of Germany.

Introduction

New sewage treatment processes now make it both possible and necessary to clean wastewater even better than previously. Future targeted quality improvements will focus on the capture of poorly biodegradable and ecologically critical residues, such as pharmaceutical remnants, chemicals, etc. The requirements specified by the European Union, which is planning a standardized European regulatory instrument in the field of water protection and plant approvals, will also play a major role.

The “Klärwerk Steinhäule” sewage treatment plant operator will need to expand the capacity of its operating site to meet these technical and qualitative challenges. Further clarifiers and a filter plant will be needed to enable the municipal sewage treatment association to expand its treatment plant into a state-of-the-art facility [1]. In the present project, exposed pressure pipelines for new underground denitrification tanks, with inside diameters ranging from DN 1000 to DN 1400 and a large range of special components, necessitated detailed advance planning with respect to stress analysis and structural design of the pipelines. Spirally wound, PE 100 large-diameter pipes were installed for sewage treatment in collaboration with an installation contractor and engineering consultants.

“Klärwerk Steinhäule” municipal sewage treatment association (Zweckverband)

Close to the Danube, down river from the “Böfinger Halde” power station, at a place known as “Steinhäule” in the district of Pfuhl, is the sewage treatment plant named after its location. The plant is operated by the “Klärwerk Steinhäule” municipal sewage treatment association, which includes the towns of Ulm, Neu-Ulm, Senden and Blaubeuren and the communities of Berghülen, Blaustein, Dornstadt, Illerkirchberg, Illerrieden, Schnürpflingen and Staig. The sewage from the catchment area is treated, cleaned and returned to the hydrological cycle by discharging it into the Danube. The whole process is carried out in accordance with statutory provisions and local authority decisions [1].

It was not until the “Böfinger Halde’ hydroelectric power station on the Danube was being built that a clear idea emerged as to the location of the sewage treatment plant. The exact site could only be below the weir or hydrolectric dam on the Danube, where, with the aid of a new feeder pipe, gravity operation was possible. So that is how the site at “Steinhäule”, which is so favorable to the development of the towns, came about. In 1957, after a two-year construction period, the joint mechanical sewage treatment plant for Ulm / Neu-Ulm commenced operation.

The plant covers an area of 11 hectares. Every day, sewage from around 400 000 population equivalents in the catchment area flows through the sewerage system into the treatment plant on the Danube. A wastewater volume of some 80 000 to 100 000 m³ per day has to be treated. Around 40 percent of this comes from industrial and commercial enterprises. The treatment process generates about 20 to 40 tonnes of sludge (dry solids) every day, which is passed on for thermal energy recovery. The entire process from the time the sewage enters the plant until the treated effluent is discharged into the Danube takes around ten hours. By way of comparison, the Danube would require about ten days to do the same job with its self-cleaning powers.

Fig. 1: View of pipe installation walkway with DN 1000, DN 1200 and DN 1400 pipelines

Construction requirements – Project description

The new denitrification tank project comprised eight cascades with feed and discharge pipes. Each cascade had to have a capacity of 2400 m³.

The following requirement profile was specified for the exposed, underground pipeline system:
Pressure pipelines with an inside diameter of DN 1000 to DN 1400 for flexible wastewater transport and distribution.
The underground pipelines were to contain special components such as branches, valves, wall ducts and reducers.
Flow capacity: 55 to 70 m³/min.
Operating temperatures: 5 and 20°C.
Permissible operating pressure / system pressure: max. 1.5 bar.
Service life: 50 years.

Selection of the pipe material

The original plan for the new treatment plant specified stainless steel as the pipe raw material. The economic and technical advantages of PE 100 pipe systems in the supply sector had been known to the treatment plant operator and the engineering consultants involved for a number of years. As a result, this plastic pipe was included as an alternative item in the bid invitation alongside stainless steel.

Cost efficiency and technical aspects of PE 100

PE 100 pressure pipes and fittings offer considerable handling and installation advantages as a result of their relatively low specific density of 0.959 g/cm³. This has a very positive effect on pipelaying costs. Spirally wound pressure pipes with a nominal diameter greater than DN 800 can be produced economically through a flexible production process [2].

The technical advantages of PE 100 pipe systems are, in particular, their good chemical resistance, high operational safety, low tendency to fouling, significantly better abrasion behavior than metal pipe materials (based on the Darmstadt method), and good weldability, which ensures permanent leaktightness of the system [2]. From an environmental perspective, the low energy required to produce PE 100 pipes and the possibility of recycling should be mentioned [3].

Verification of long-term strength

PE 100 and PE 80 pipe systems have proved their worth over many years for the transportation of gas, water, wastewater and groundwater-polluting media on account of their outstanding performance, cost efficiency and operational safety.

An international standard (ISO 9080) for thermoplastics is now available, which describes an extrapolation method enabling scientifically based predictions to be made about the long-term strength of thermoplastic pipe materials.

This extrapolation method received glowing confirmation in autumn 2006. Test pipes installed in October 1956, which were produced from laboratory quantities supplied by the former Hoechst AG in Frankfurt, have withstood the internal pressure at 20°C to this day and so confirmed the correctness of the Arrhenius equation [4].

Manufacturers and users of pipe systems have three high-density polyethylene (HDPE) materials at their disposal: *Hostalen* GM 5010 T3 black (PE 80), *Hostalen CRP* 100 black (PE 100) and *Hostalen CRP* 100 RESIST CR black (PE 100). These multimodal, third-generation HDPE pipe materials are manufactured by LyondellBasell at its production site in Wesseling am Rhein in a multi-stage polymerization plant by the ACP process [2].

Pipe and pipe fitting production

FRANK GmbH, headquartered in Mörfelden, has over 40 years' experience with PE pipe materials and is one of Europe's largest spirally wound pipe manufacturers, with branches in Poland and also New Zealand.

The pressure pipes, elbows and branches required were produced by Frank's two subsidiaries at Wölfersheim. Thanks to the flexible, state-of-the-art production facilities for spirally wound pipe at Wölfersheim, customer-specific pipe dimensions in PE and PP up to DN 3500 can be manufactured there without any problem.

To minimize installation costs at the construction site, whole segments (pipe and fitting) were prefabricated at Wölfersheim. These components were produced in special lengths from 4 to 8 meters and transported to the construction site on flat-bed trucks.

Stress calculations for the pressure pipes, elbows and fixed flange joints were carried out by Frank Deponietechnik in collaboration with engineering consultants Ingenieurbüro Pöltl. The calculations were checked by the LGA in Nuremberg and by Dr.Ing. Dietmar H. Maier in Karlsruhe. The supporting points were calculated by engineering consultants Ingenieurbüro Brandolini & Seitz of Ulm.

In pipe manufacture, it is necessary to differentiate between extruded pipes (pressure pipes and corrugated pipes) as per DIN 8074/75 and spirally wound pipes as per DIN 16961, which are used mainly in nominal diameters from 600 mm upwards.

Production of extruded pipes

Plasticated PE material is shaped into a pipe in the die head. While still soft, the plastic pipe is then passed through a sizing unit, where it is adjusted to the required outside diameter by vacuum application. Downstream water tanks then cool the pipe to ensure the necessary dimensional stability. At the end of the processing line, there is a haul-off unit, whose speed can be used to regulate pipe wall thickness. In this way, a "continuous pipe" is produced, which can be cut to the required length with a suitable saw cutter (Fig. 2).

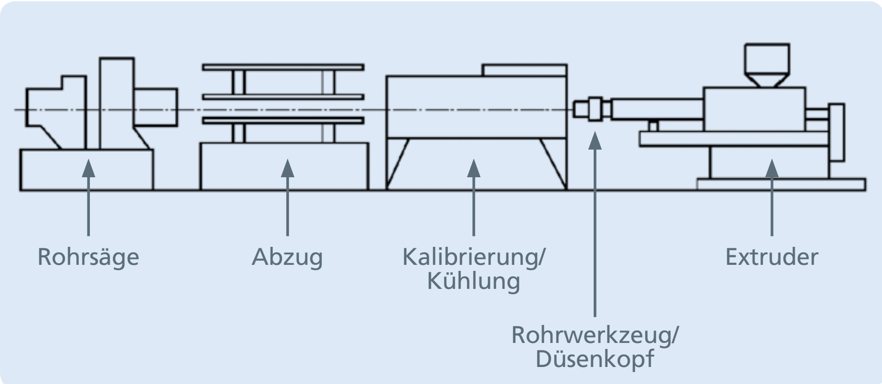


Fig. 2: Production process for extruded pipes as per DIN 8074

Production of spirally wound pipes

Spirally wound pipes are produced by a track-mounted mobile extruder. The molten PE or PP material is spirally wound as a continuous, overlapping tape onto a metal mandrel. A second, functional and/or inspection-friendly inner layer can be applied using a coextruder.

The pipe is sized by the metal mandrel, which determines the inside diameter (DN) of the pipe. The pipe is slowly cooled by a fan. This reduces internal stresses caused by volume shrinkage and the production process.

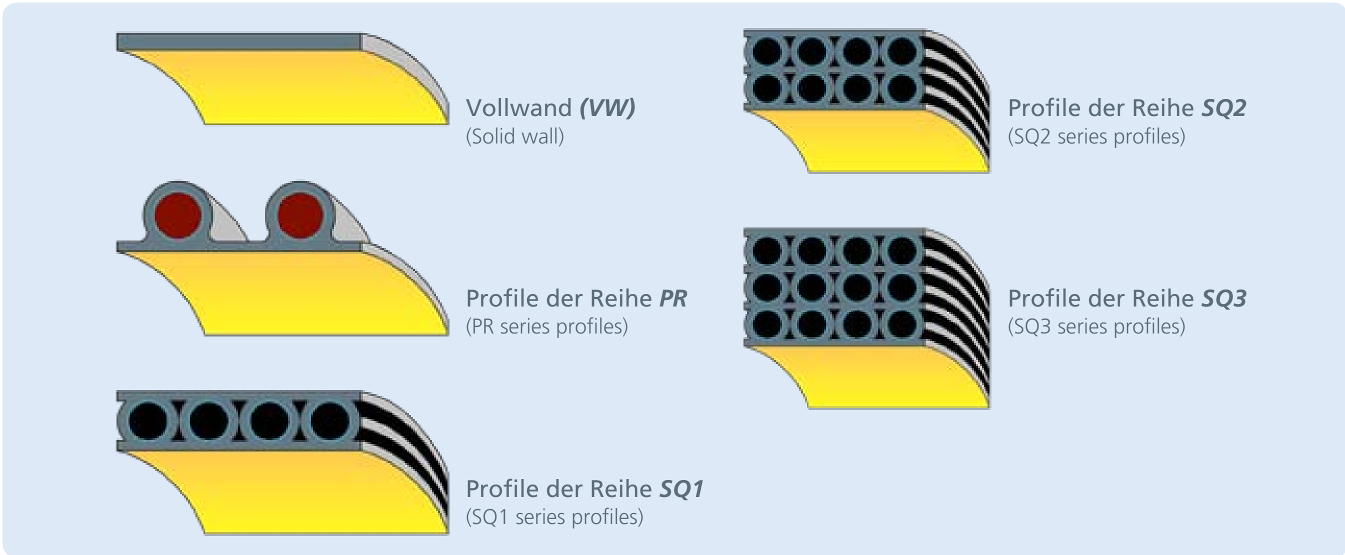
By winding the tape in multi-layers and varying the amount of material applied, different wall thicknesses can be obtained (Fig. 3).

Fig. 3: Production of spirally wound pipes at FRANK & Krah GmbH as per PAS 1065 / DIN 16961

With spiral winding, it is also possible to build up a pipe wall structure with hollow profiles. These are wrapped with molten tape and wound onto the base layer. In this way a unitized, homogeneous bond is obtained.

Profiles of various sizes can be spirally wound with different spacing to give many possible variants. It is therefore possible to optimize the pipe structure for the specific installation site and service stresses (Fig. 4).

Fig. 4: Spirally wound pipe profiles [5]



Engineering considerations

In view of the construction project requirements, it was necessary to carry out detailed advance planning with respect to stress analysis and the structural design of the pipelines, taking account of the exposed pipeline installation. Among the factors to be considered were possible internal pressure stress, thermal expansion in relation to the required fixed-point structures, and the distances between supports. Relevant stress data for PE 100 were provided by the raw material manufacturer.

Internal pressure stress

In designing pipes with relatively large dimensions, internal pressure must always be taken into account. Here a distinction needs to be made between continuous operating pressure and short-term test pressure. To calculate the necessary minimum wall thickness (s_{min}), the boiler formula is used [5].

$$s_{min} = \frac{p \cdot d}{20 \cdot \sigma_{zul} + p}$$

s_{min}	Mindestwanddicke = Minimum wall thickness	[mm}
p	Betriebsüberdruck = Operating pressure	[bar]
d	Rohraussendurchmesser = Pipe outside diameter	[mm]
σ_{zul}	Berechnungsspannung = Design stress	[N/mm²]

Figure 5: Boiler formula to calculate the pipe wall thickness [5]

Temperature-dependent linear thermal expansion

Another influencing factor with very long pipe runs is the problem of temperature variations giving rise to length changes in the system. The magnitude of the length change is influenced by the linear thermal expansion coefficient α, which describes the behavior of a material in relation to temperature [5].

The amount of thermal expansion due to temperature variations is relevant to selection of the pipe supports and fixed pipe connections with wall ducts. The introduction of stress into the stainless steel valves as a result of pipe expansion had to be avoided at all costs, since the structural design analysis showed that the unhoused slide gate valves should not absorb any axial forces from the pipelines.

$$\Delta L_T = \alpha \cdot L \cdot \Delta T$$

ΔL_T	Längenänderung infolge Temperaturänderung = Length change due to temperature change	[mm]
α	linearer Ausdehnungskoeffizient = Linear thermal expansion coefficient	[mm/m·K]
L	Rohrlänge = Pipe length	[m]
ΔT	Temperaturdifferenz = Temperature difference	[K]

Design in the slide gate valve section

Since the unhoused slide gate valves cannot absorb any axial forces from the pipeline, a design with a fixed point and extension piece (fixed flange fittings made from stainless steel) was chosen to achieve stress-free mounting of the slide gate valves (Fig. 6).

The pipe ends were provided with a milled groove and rigidly mounted on a support. Through this fixed point design, the forces generated by temperature-dependent linear expanson could be absorbed and diverted around the flange-connected slide gate valve.

Stress calculations

Stress calculation and pipeline system design were very time-consuming. The usual numerical methods as per DVS 2210-1 enabled the sections of pipeline without fittings to be verified. In particular, the calculations for internal pressure stress, fixed point forces due to temperature-dependent linear expansion, and distances between the supports could be carried out in this way. The results of these calculations led then to structural design of the straight pipes between the fittings. It was found that the PE 100 pipeline could be laid with the same distances between the supports as a stainless steel pipeline. However, the high thermal expansion of PE (α = 0.18 mm/m*K) required considerably increased calculation effort. But, as already described, this calculation then made it possible to design the fixed points in the slide gate valve section so as to divert the axial forces and ensure stress-free installation of the slide gate valves.

Fig. 6: Flanged pipe with fixed flange fitting made from stainless steel, allowing diversion of axial forces around the slide gate valve

Finite element analysis of the fittings

The fittings, such as tees, elbows, reducers and fixed flanges had to be considered separately. These fittings were all manufactured from solid-wall spirally wound pipe so that the required wall thickness could be exactly produced. The verification was carried out with the aid of finite element analysis. This method can be used to solve problems from a wide variety of disciplines. Common to all these calculations is the fact that the component is divided into a large but finite number of smaller elements. With these elements, the forces acting on the component are defined. So for any geometry, the required wall thickness can be determined.

For the 90° pipe branches, deformation, maximum stresses and other aspects were studied using the FE model (Fig. 7). Overall, very high stresses occur but these act most strongly on the outer sides of the bend. The deformation of the concrete-encased branches due to thermal expansion was also calculated in this way.

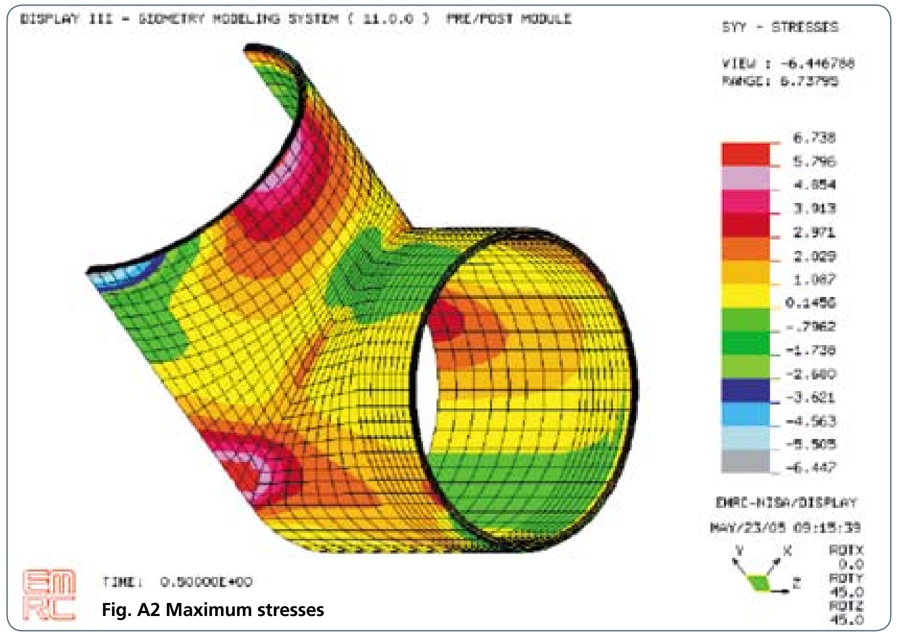


Fig. 7: Finite element model, tee DN 1400, LGA Nuremberg [6]

The strongest deformation forces also act on the outer sides of the bend (Fig. 8). For these reasons, the 90° pipe branches much be designed with considerably greater wall thickness (soild wall thickness of 42 mm) than straight pipe.

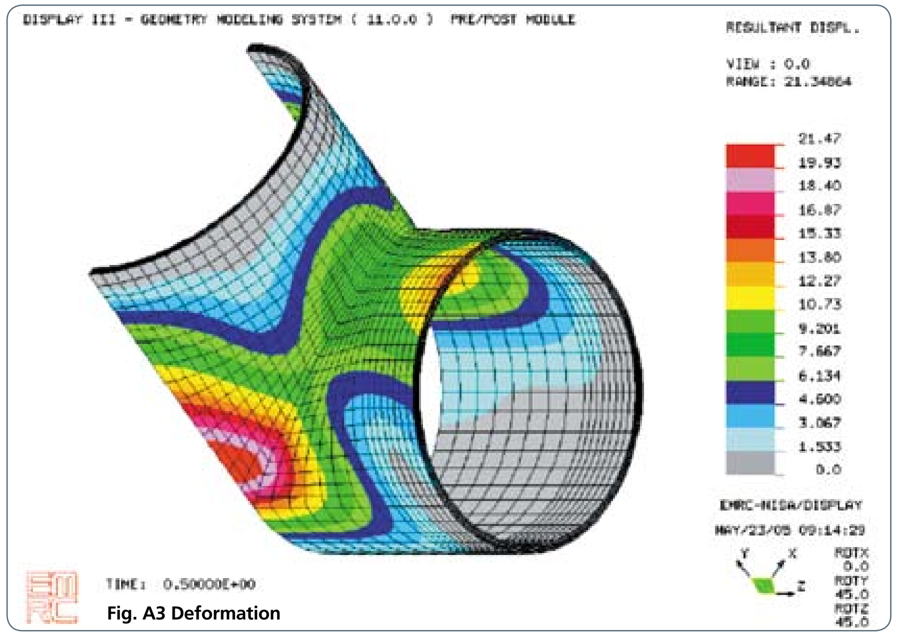


Fig.8: Finite element model, tee DN 1400, LGA Nuremberg [6]

Completion of the construction project

Following all the considerations, calculations and analyses, installation of the PE 100 pipes and fittings in the installation walkway between the denitrification tanks was started on July 23, 2006. The entire installation work was successfuly completed in only 2 months (Fig. 9).

The experience gained in the Steinhäule installation project can be used for other projects and shows that PE 100 is more than an alternative to stainless steel in pipeline construction.

Acknowledgement

The authors would very much like to thank Zweckverband Klärwerk Steinhäule, PM Engineering, LGA in Nuremberg, the contractor KG from Nellingen and the consulting engineers KS in Merklingen and Brandolini & Seitz in Ulm for providing photos, illustrations and information.

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