SEALING SEWERS FOR OIL INDUSTRY REFINERIES IN GERMANY USING FLOODGROUTING: A CASE STUDY

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ABSTRACT

Since 1992 Sanipor®- floodgrouting technology has been used for sealing industrial - gravity sewer pipes in Germany. Being a holistic rehabilitation system it can be applied from one entry point for any kind of structurally stable pipe irrespective of shape, gradient or material including laterals and manholes in one operation.

The sealing itself takes place in the bedding of the pipes when a silicate - like matrix is binding soil particles and consolidating the ground around the defects.

As an additional effect, an in situ encapsulation of pollutions within the bedding takes place as the silicate gel - soil conglomerate immobilizes contaminations in-situ.

Both technological and chemical capabilities of the Sanipor®-floodgrouting system were needed and utilized in the following project :

Location/Date:	Esso Oil-Refinery in Ingolstadt, Bavaria, Germany, 1993
Pipes:	1,293 meter (4242.12 ft) castiron sewerpipes; diameters: 150,200,300 mm
Manholes:	96 concrete-manholes
Problem:	Exfiltration of oil contaminated sewage
Duration of work:	14 working days
Volume of pipes:	16,213.42 gal (total)
Volume of manholes:	24,472.84 gal (total)
Injection Volume:	2,219.28 gal of Sanipor S-1 and 1,651.25 gal of S-2 (total)
Varranty:	5 years - no reclamations since 1993

The extremly small amount of used (lost) injection materials - less than 10 % - is owed to the cast iron pipes and the oil polluted soil. In order to avoid further enviromental pollution of soil and groundwater, this kind of No-Dig technology gives a very quick and cost effective tool in the hands of sewer managers in cases of infiltration.

Keywords: Sewer Rehabilitation, Oil Industry, Castiron Pipes, Concrete Manholes

INTRODUCTION

This paper has three targets:

1. To describe the enviromental regulations in Germany in relation to sewer rehabilitation.
2. To introduce the enviromental, chemical and physical properties of a silicate based floodgrouting technology called Sanipor® in order to understand why this kind of material is suited for sealing sewers in the oil industry.
3. To show the application with the help of a 9 year old case study regarding the technological and economical aspects of floodgrouting in the rehabilitation of industrial sewers.

1. LEGAL BACKGROUND OF ENVIROMENTAL REGULATIONS IN GERMANY

Since the late eighties in Germany enviromental pollution is punishable under Enviromental Legislation. [1] Under section §324 and §324 a of the Criminal Law Statute - book (StGB) the unauthorized contamination of natural waters and soil is defined and prohibited.
The punishment may reach from 3 up to 5 years of imprisonment, even for civil servants or people who neglect their adminsitrative duties and neglect to rehabilitate leaking drainages.
The pollution of groundwater with wastewater - even by letting sewers leak - is regarded to be a criminal act.
In order to secure the effectivity of this law, additional legal regulations in the form of German and European Norms and several Waterlegislations in all German Federal States have been introduced and harmonized.[2] [3]
One of the most important is the German Industrial Norm called DIN 1998 part 30 which is under renewal currently: "Wastewater Drainages in Buildings and Properties - Rehabilitaion".
This Norm lays down that industrial sewers have to be TV inspected every 5th year and all sewers have to be proved by 2004. In case defects are detected rehabilitation of the pipes has to take place.
The Discription of Defects are regulated in the (Euronorm and German Norm) EN DIN 13508-2 and the Evaluation of Defects in the EN 13508 .

What the wastewater and oil industry is especially concerned about is - as one example - the Bavarian Federal State Waterlegislation [4] defines the limits of toxic- and pollution contents in wastewater coming from oil industrial plants, and may be drained into public sewer systems as below:

Table 1: Limits of toxic and pollution contents of wastewater from oil industry

	random sample or mixed samples of 2 hours mg/l
Phenolindex after destillation and extraction of colouring	0,15
Adsorbable, organicly bound halogens	0,1
Sulphid- and Mercaptan- Sulphur	0,6
Cyanid, easily releasable	0,1

The limits for wastewater which have been treated in the industrial (privately operated) treatment plant in the oil industry and may be discharged into natural waters (rivers) are shown in Table 2:

Table 2: showing limits of toxic and pollution contents of oil industrial effluents after treatment

	random sample or mixed samples of 2 hours mg/l
Chemical need of oxygen	80
Biochemical need of oxygen in 5 days	25
Nitrogen total as a sum of Ammonium- Nirtide - and Nitrate -compounds	40
Phosphorus total	1,5
Hydrocarbons total	2

Untreated wastewaters flowing in the sewers of oil refineries have generally higher contamination rates as given by the above limits and may not pollute the surrounding ground and waterways through leaking sewer pipes.
In accordance with the German legislation, Esso Germany, with its two main refinieries in Ingolstand and Karlsruhe, decided in 1993 and 1994 to remedy the leakages within their pipes and manholes. Continous rehabilitation is taking place still today.
Among the No Dig rehabilitaion methods for pipes with small diameters - 150 to 350 mm - the approved floodgrouting system chosen was Sanipor®. (See point 3 of this paper)

2. ENVIROMENTAL IMPACT OF THE SANIPOR® FLOODGROUTING SYSTEM

In order to avoid additional pollution to the soil or groundwater the sewer sealing grout has to be enviromently friendly itself and should not be in harmful as the chemical interacts with the existing contaminations.

The enviromental impact of a soil stabilization and sewer sealing product such as Sanipor® is evaluated on the basis of the extent to which it could give rise to a continuous emission of heavy metals, toxic, presistent organic chemicals and high pH values into the enviroment.
The major componets of the system are inorganic silica bearing compounds which on dilution rapidly depolymerize into molecular species indistinguishable from naturally occuring dissolvent silica. The organic components, of which only minor proportions are likely to reach the local enviroment of the sewer, are non- toxic for soil and water-organisms and are highly biodegradable.[5] The sodium silicate sol-gel reaction takes place in the bedding and the primarly high pH value subsides typically within 72 hours. Long lasting alkalinity would reactivate heavy metals and be harmful to the biology of the soil.

In 1994 Sanipor® sought official approval for both the process and the solutions by submitting samples to relevant institutes at the Hygeneinstitut Gelsenkirchen or the Institute für Wassergefährdende Stoffe an der Technischen Universität Berlin. [5] It was stated that the Sanipor® System was enviromentally compatible and suitable for use in both non-water and water-bearing ground.[6]

According their national legislations, several other Technical and Enviromental Institutes in GB, Netherlands, Australia, Hungary, Austria, South Africa have approved the enviromental friendliness of the system.[7]

2.1. CHEMICAL STABILITY

At the Research Laboratory of Inorganic Chemistry, Hungarian Academy of Sciences tests have been performed in order to verify the chemical and physical properties of the silicate grouting material within Sanipor®. [8]

The gel and matrix formed consists almost entirely of silica. As such it is resistent to chemical reactants occuring in sewers. To test corrosion resistance, small test pieces were prepared by solidifying a given soil with Sanipor® solutions. The soil was selected in accordance with DIN 18 196 which contains soil classification for civil engeneering purposes.

A sample of soil of mixed-size particles containing clay as fine grains was used to prepare the test pieces. It corresponded to a soil of GT-types (see DIN 18 196 Table 5.)

The test pieces were then totally immersed for 30 days at 28 °C in the following solutions

Table 3: showing corrosion tests

Corrosive Solution	PH	No.test runs	change in weight
5 % $H_2 SO_4$ (sulfuric acid)	<1	5	+ 0.2 %
5 % NaOH	>13	5	- 56.7 % after 3 days
Michaelis Buffer	11	5	+0.29 %
6% Saline Water			
2% $Na_2 CO_3$ (sodium carbonate)			
Various organic solvents, benzene, toluene and xylene			

(Michaelis Borate buffer solutionis a 1 : 1 mixture of 0.1 M NaOH + 0.2 M $Na_2 B_4O_7$ solution)

No corrosion or degradation was shown except with the 5 % NaOH solution. The outer part of the test pieces was disintegrating. Masses after the treatment relate to the mass of intact core of piece. Only under such alkaline pH ≥ 11 - sewage or soil- conditions Sanipor® can not be applied.

2.2. ENCAPSULATION CAPABILITY OF SILICATE GROUTING

The silicate matrix of Sanipor® grouting is binding not only the ground particles but also contaminations in the soil, as the Hygeneinstitute of Gelsenkirchen has explained in its enviromental assessment. [5] A kind of in situ encapsulation and immobilisation of pollution sources takes place with this type of chemical grouting.

For the areas of oil industry it is a very important aspect that in oil polluted soil the S-1 component is acting as an emulgator, being an organic watery solvent. The organic particles (drops) in the pores will be both replaced by, and encapsulated into the silicate - conglomerate. The created silicate-matrix is hydrophyl and lyophob, which means that it adsorbs the surroundig water on it´s outer and inner surface. The result is that the grout is repelling organic materials such as benzene, gasoline or oil.

2.3. WATERTIGHTNESS

The sealing ability of any grout is dependant on its watertightness. This kind of testing was also undertaken in the Research Laboratories of Inorganic Chemistry in Budapest in accordance with the German regulations. [8] In German civil engineering watertightness is usually given in terms of volume straining through the walls and connections of a tube for 15 minutes (see DIN 1230 Part 2):

The volume of water consumed for a 15 minute test was so small for the Sanipor® test pieces that it could not be measured properly. Therefore, tests on watertightness were performed for 24 hours. Due to the particular measuring arrangement, watertightness was calculated by Eq.(1):

$$W_d = \frac{4 \cdot V_d}{d^2 \cdot \pi} \qquad (1)$$

Where,

W_d water strained through 1 m² for 1 day, $l \cdot m^{-2} \cdot d^{-1}$.
V_d water consumed for the 1 day test, $l \cdot d^{-1}$.
d diameter of test piece, m
l length of the testpiece

It is also usual to express watertightness in terms of impermeability factor (*k*) defined for cylindrical test pieces as follows:

$$k = \frac{4 \cdot V_t}{d^2 \cdot \pi \cdot t} \qquad (2)$$

Where,

k impermeability factor, $m \cdot s^{-1}$.
V_t water consumed for the time t, m^3.
d diameter of test piece, m
t duration of tests, s.

In this particular case $d = 60$ mm $= 6 \cdot 10^{-2}$ m and $t = 24$ h $= 8.64 \cdot 10^4$ s.
It follows from Eqs. (1) and (2) that

$k = 1.157 \cdot 10^{-8} W_d$

if k is expressed as $m \cdot s^{-1}$ and Wd is given as $l \cdot m^{-2} \cdot d^{-1}$.

Table 4: summary of test results

V_d ($l \cdot d^{-1}$)	0.0014
W_d ($l \cdot m^{-2} \cdot d^{-1}$)	0.486
k ($m \cdot s^{-1}$)	$5.6 \cdot 10^{-9}$

During the test a pressure of 0.5 bar correspondig to a watertable of 5 m was applied.
On the basis of above data, watertightness of Sanipor® sealing corresponds to that of a low grade conrete.

3. APPLICATION

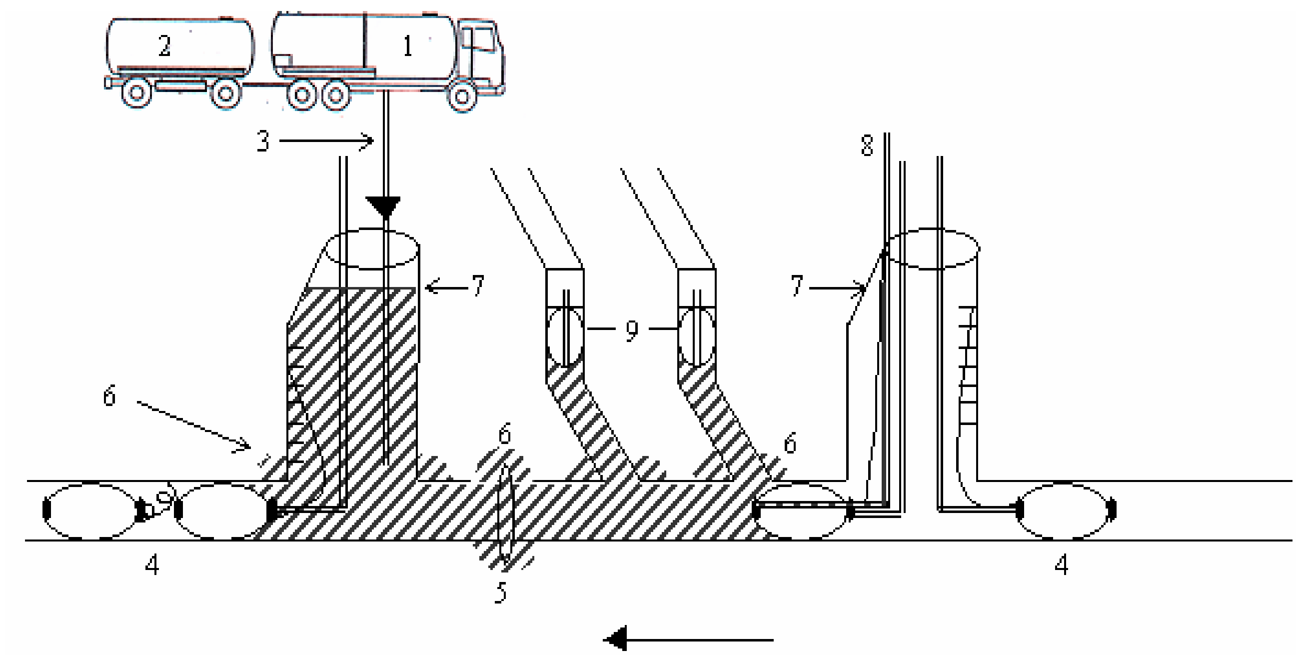
[1] Sanipor® is a holistic solution, a sewer rehabilitation system which can be used from one entry point for mainlines, laterals, underslab branches and manholes in one operation.

Any kind of pipe irrespective of shape, gradient or material can be sealed as long as it is structurally firm.

The injection technology by flooding is simple as it works basically on the laws of physics and chemistry. The injection is possible with the help of hydrostatic pressure and the reaction is a soil-gel reaction of liquid dispersions of silicates.As each and every daily project is different, the general modus of the technology is described as follows.

The sewer, after being cleaned by flushing with a high pressure water jet is, together with the laterals, closed by pneumatic stoppers. CCTV inspection and a water drop test give a clear picture about the condition of the pipe´s structure and permeability.

With access through manholes, the system of mainline, laterals and underslab branches are filled with solution S-1 up to street level to force the solution, by hydrostatic pressure, through the defects into the surrounding ground of the sewer pipes. (Figure 1)



(1) Tanker with S-1 (2) Tanker with S-2 (3) Tube of S-1 (4) Dubble securtity plug
(5) Pipe-sleeve(6) Exfiltration of S-1 (7) Filling level of S-1 (8)-(9) Ventilation through plugs
Figure 1: **showing the flooding with S-1 up to street level**

When optimum penetration has been achieved after about one hour the S-1 solution is rapidly removed, leaving the defect zones saturated. (Figure2) Remark: The amount of injected material is depending on following circumstances.

- The porosity of soil, exfiltration or infiltration of groundwater
- The quantity of leakages in the pipes
- The hight of hydrostatic pressure
- The time of flooding periodThe technology has to be adjusted to accommodate varying field conditions.

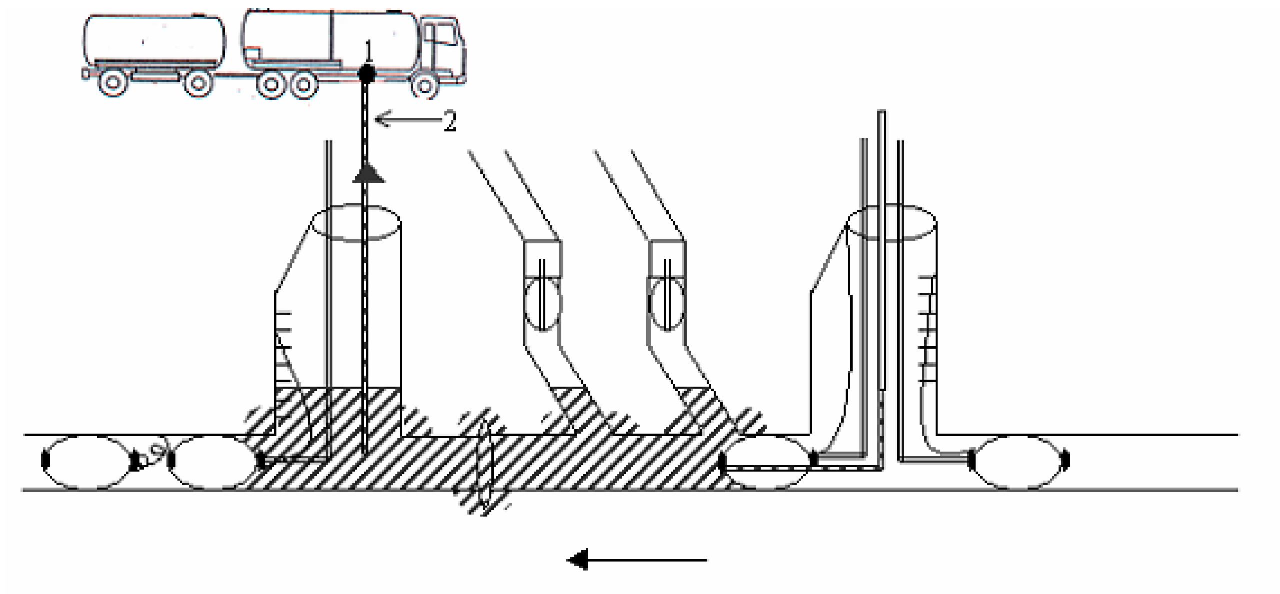
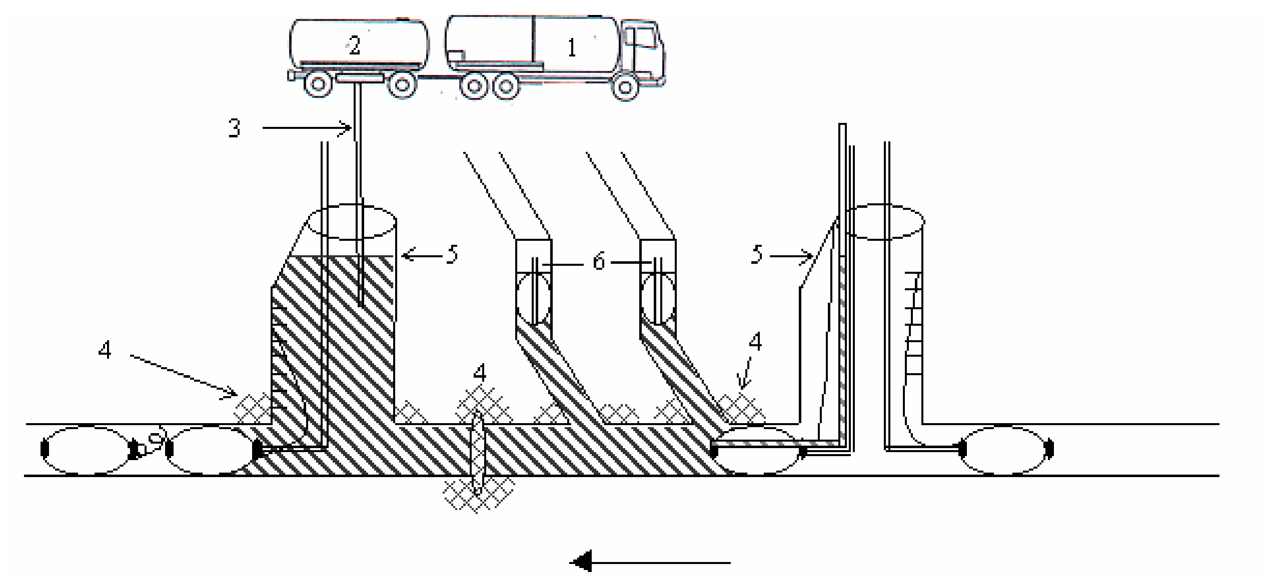


Figure 2: S-1 is pumped back into it´s tanker

After short flushing, the same section is immediately reflooded with the less viscous S-2 which reacts with S-1 in the backfillzone.This starts to form a sandstone-like matrix, binding the soil particles and consolidating the ground around the defects.(see Figure 3 (4)) When the reaction is complete and the watertightness established, Solution S-2 is pupmed out. After flushing, the sewer is returned to service. The effectiveness of repair is confirmed when the level of the S-2 solution, as measured in the manhole, remains constant - comparable to a hydrostatic test.(Figure 3)



(1) Tanker with S-1 (2) Tanker with S-2 (3) Tube for S-2 (4) Exfiltration of S-2 and mixing with S-1 (5) Constant filling level of S-2 (6) Ventilation of laterals
Figure 3: **S-2 exiltrates into bedding and creates the watertight matrix (4)**

3.1. ECONOMICAL ASPECTS

In principle the cost factors of floodgrouting are the daily fixed price of equipment and manpower and the loss of injected system components S-1 and S-2.
When the circumstances and the planning allow flooding a network of pipes linked within a section , the labour time is minimized and the effectivness optimized. (Figure 4) This is mostly the case with industrial drainages. In addition , the loss of S-1 and S-2 is usually very low in oil polluted areas. (Table 5) Both factors indicate floodgrouting to be fairly economic in the sewer rehabilitation work especially in the oil industry.
Approximate costing for the below described project would be about € 110,000.00.

3.2. REFINERY INGOLSTADT

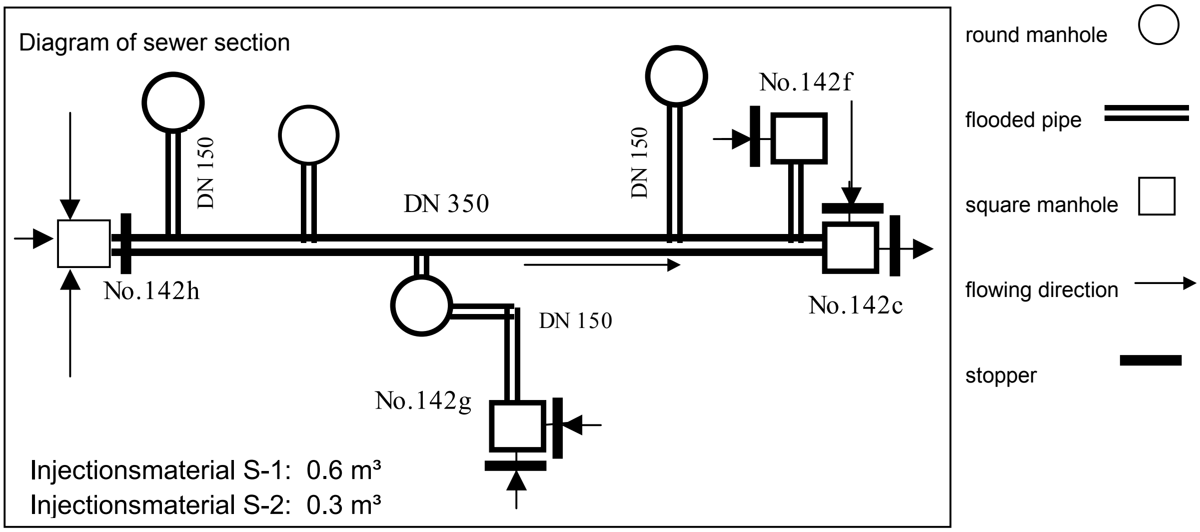
Location/Date:	Esso Oil-Refinery in Ingolstadt, Bavaria, Germany, 1993
Pipes:	1,293 meter (4242.12 ft) castiron sewerpipes; diameters: 150,200,300 mm
Manholes:	96 concrete-manholes
Problem:	Exfiltration of oil contaminated sewage
Damages:	Leakages at the flanges and cracks within the concrete manholes, no structural defect
Duration of work:	14 working days
Volume of pipes:	16,213.42 gal (total)
Volume of manholes:	24,472.84 gal (total)
Injection Volume:	2,219.28 gal of Sanipor S-1
	1,651.25 gal of S-2
Varranty:	5 years - no reclamations since 1993

Figure 4 is an example of one day´s job report showing the topography of pipes and the flooding cycles. The Diagram shows the connected pipes with the round and square shaped manholes. With the help of 5 pneumatic stoppers the section was separated for flooding from the rest of the sewer system. Removing deposits with hot water and high pressure cleaning jets were necessary before starting the flooding with system components. All involved parts of the sections were filled and sealed together. Over 8 hours two cycles were performed. This means that the change of S-1 and S-2 components was repeated once more. One flooding period took about 55 minutes time.

The loss of injection material was very low what in oil contaminated soil can be regarded as ususal. The watertightness of ironcast pipes is another reason for the little amount of exfiltration. The refillment of components, after 25 to 30 minutes, were in order to maintain the hydrostatic level as high as possible. The quantity of lossed injection material is always related to the volume of the whole system beeing flooded. The rate of loss of S-1 to S-2 is generally 1: 0.5 but can differ as in this case Table 5: in the inner part of the refinery of Ingolstadt, where the diameter of the pipes were dominantly between 150 and 350 mm, Sanipor® was used to seal a extensive branching system. Other trenchless technologies were not available which could reach all the laterals which were often curved or bent.
In the outer sections where the diameter became 600 to 1400 mm, Liners were inserted. The daily quantity of sealing can be seen on Table 5. The technological aim was to gather as many parts of the system into one section as possible in order to save working time. The maximun was 205 m of pipe with 15 manholes and cleanouts a day.

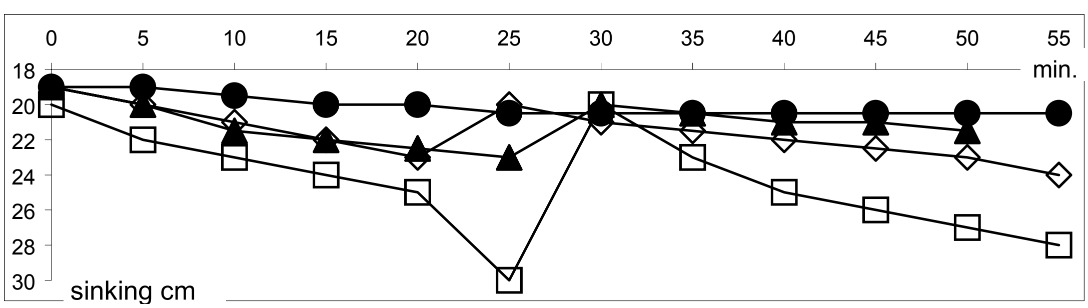
Sanipor - Sealing Protocol: working with 2 cycles

Esso, Ingolstadt, Refinery, September 14.1993



Working time: 8 h

Time (min)	sinking (cm) 1. cycle S1	sinking (cm) 1. cycle S2	sinking (cm) 2. cycle S1	sinking (cm) 2. cycle S2	sinking (cm) 3. Cycle...
0	20	19	19	19	
5	22	20	20	19	
10	23	21	21.5	19.5	
15	24	22	22	20	
20	25	23	22.5	20	
25	30	20	23	20.5	
30	20	21	20	20.5	
35	23	21.5	20.5	20.5	
40	25	22	21	20.5	
45	26	22.5	21	20.5	
50	27	23	21.5	20.5	
55	28	24		20.5	



pipes:			manholes:		
Ø mm	length(m)	volume m³	Ø cm	dept (m)	volume m³
350	*53*	*5.10*	*150 X 150*	*1.6*	*3.60*
150	*64*	*1.13*	*2 X 60 X 60*	*1.6*	*1.15*
			4 X DN 60	*1.2*	*1.36*

Figure 4: Daily Job Report

Table 5: Showing the daily amount of floodgrouted sewers and manholes

ESSO Ingolstadt	manholes		pipes			loss of chemicals		Working hours
	piece	Volume m³	DN / Length		Volume m³	S1 m³	S2 m³	
6 th of Sept 1993	3	11,04	200 mm ×	55,5 m				
			300 mm ×	42 m	4,710	0,2	0,3	10,5
7 th of Sept 1993	7	4,5	150 mm ×	13 m				
			300 mm ×	40 m	3,056	0,6	0,75	10
8 th of Sept 1993	2	0,4	150 mm ×	16 m				
			350 mm ×	39 m	4,033	0,4	0,65	9,5
9 th of Sept 1993	10	7,3	150 mm ×	49,5 m				
			200 mm ×	24 m				
			300 mm ×	29 m				
			350 mm ×	62 m	9,639	0,7	1,15	12
10 th of Sept 1993	3	4,6	150 mm ×	15 m				
			200 mm ×	29 m	1,176	0,1	0,15	8
13 th of Sept 1993	10	5,27	100 mm ×	4 m				
			150 mm ×	22 m				
			200 mm ×	29 m				
			250 mm ×	30 m				
			300 mm ×	41 m	5,699	0,6	0,3	10,5
14 th of Sept 1993	10	11	150 mm ×	67 m				
			200 mm ×	33 m				
			350 mm ×	53 m	7,316	0,6	0,3	8
15 th of Sept 1993	8	7,09	150 mm ×	36 m				
			200 mm ×	50 m				
			350 mm ×	17 m	3,841	0,8	0,3	10
16 th of Sept 1993	8	5,6	150 mm ×	46 m				
			200 mm ×	18 m	1,378	0,3	0,15	10,5
17 th of Sept 1993	15	8,9	150 mm ×	35 m				
			200 mm ×	95 m				
			300 mm ×	75 m	8,900	0,6	0,3	9
4 th of Oct 1993	3	5,18	150 mm ×	26 m				
			300 mm ×	54 m	4,274	0,2	0,1	9
5 th of Oct 1993	6	10,13	150 mm ×	4 m				
			200 mm ×	16 m				
			300 mm ×	24 m	2,269	1	0,5	9,5
6 th of Oct 1993	9	8,3	200 mm ×	47 m				
			300 mm ×	33 m	3,807	1,5	0,7	9,5
7 th of Oct 1993	2	3,32	150 mm ×	8 m				
			300 mm ×	16 m	1,272	0,8	0,6	11
14 days	**96**	**92,63 m³**		**1293 m**	**61,368 m³**	**8,400 m³**	**6,250 m³**	**137,00 hours**
						5,45 % S1 and 0,744 S2-Rate		

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