COMPRESSING MINE SALTED WATERS INTO SANDSTONES OF THE UPPER SILESIAN SANDSTONE SERIES

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INTRODUCTION

The inflow of heavily saline waters to mine headings, and in consequence their discharge into surface streams, is a significant problem to the Jaworzno coal mine both from the environmental and economic point of view.

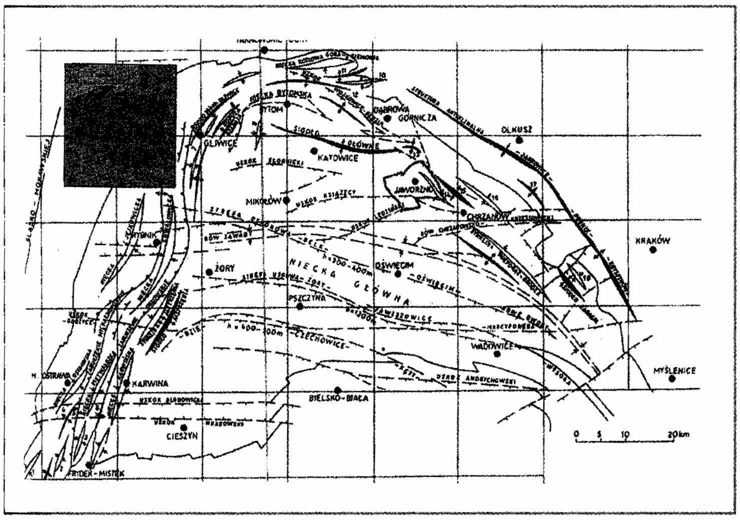


Figure 1. Localization of coal mine Jaworzno.

In 1991, a "Technological project on salt waters inflow reduction to the Jaworzno Coal-mine" was developed. In it was adopted the concept of salt waters being compressed into a reservoir located within the Upper-Silesian sandstone series and isolated from mine headings. The "Technological project on salt waters inflow reduction to the Jaworzno Coal Mine", the engineering and economic assumptions for the investment task called "Pilot installation for compressing salt waters into the Upper-Silesian sandstone series deposits" and the "Hydrological research project for pilot absorptive boreholes CH-1, CH-2 and CH-3-3" approved by the Minister of Environmental Protection, Natural Resources and Forestry were the basis for performing two compressing boreholes CH-2 and CH-3 from underground headings and boreholes CH-1 drilled from the surface.

While the boreholes were being drilled, a hydrological research was conducted on the current basis of water-bearing horizons, water samples were taken for chemical analyses and rock samples for laboratory tests aimed at determining the possibility of saline reception by absorptive layers as well as the capacities of the compressing boreholes.

In parallel with the drilling, works were conducted in relation to assembly of the installation for transporting saline from the underground reservoir to the headings, where boreholes (injection chambers) were made. The boreholes were equipped with saline conditioning filters, pumps and control equipment. A numerical model of the coal mine was developed for the needs of planned monitoring. In December 1998, trial compressing into the CH-3 and CH-2 boreholes was carried out.

GEOLOGICAL CONDITIONS

The Jaworzno Coal-mine area is localised in eastern, folded / block part of the Upper-Silesian coal basin, to the south of the eastern slope of the main saddle. There are Quaternary, Tertiary, Triassic and Carboniferous formations in the geological structure of the documented area.

Quaternary

The Quaternary formations are Pleistocene and Holocene. The Pleistocene is sanded-up boulder clays as well as sands and gravels of the river and glacier accumulation. The Holocene formations are contemporary river deposits, both medium- and fine-grained dune sands and loams. The deposit thickness is very much differentiated and it varies in the range of 3.0 m on hills an up to 40.0 m in the river valley.

Tertiary

The Tertiary formations occur in the eastern part and partially southern part of the Jaworzno Coal Mine mining area. These are Miocene sediments developed in the sea facies as clays with chips of limestones and sandstones. The formations maximum thickness is ca. 90 m.

Trias

The Triassic formations appear in the eastern and southern part of the coal-mine mining area. They occur disconformably on the Carboniferous formations. The thickness of Triassic deposits in some places comes up to 200 m.

Upper Carboniferous

Cracow sandstone series (Westfal B/C)

It is developed in the form of varigrained sandstones with a slight share of claystones and mudstones which primarily accompany coal deposits. The thickness of Cracow sandstone series in the coal mine area range from 400 m in the north to 700 m in the southern and south-eastern part.

Mudstone series (Westfal A and Westfal B)

It is primarily composed of impermeable mudstones, clay-stones and numerous coal and coal shale beds. It makes an isolating screen between the Upper-Silesian sandstone series and the Cracow sandstone series. The sandstone layer occurring in the next-to-bottom part (SM) has been included into absorptive strata of the Upper-Silesian sandstone series (GSP). The mudstone series thickness in the coal mine area varies between 400 and 550 m.

*Upper-Silesian sandstone series - **absorptive strata** (Westfal A + Namur A, B and C).*

The series profile is dominated by varigrained sandstones, frequently cracked and "disked". The thickness of the Upper-Silesian sandstone series (absorptive strata) in the coal-mine area varies between 40 and 140 m.

Border strata (namur A)

The bored part of clearing strata is predominantly composed of packages of impermeable mudstones and clay-stones. The border strata roof has been localised in the bottom of the sandstone, which is under a conglomerate layer or under the equivalent of the bed marked as 510.

TECTONICS

The "Jaworzno" Coal-mine is situated in the eastern part of the Upper-Silesian Coal Basin. The proximity of the Coal Basin eastern border decisively affects the tectonic deformation. The tectonic and physical analyses of the area indicates the possibility of separating at least four main directional fault systems, which divide the deposit into a dozen or so tectonic blocks. The Carboniferous strata generally dip in the southern direction at slight angles from 5° to 15°. The absorptive boreholes have been located in two bordering tectonic blocks separated with the Jan Kanty-Bory fault downthrusting in the western direction. The size of the Jan Kanty-Bory fault downthrust ranges from 200 to 220 m. The surface borehole CH1 and the exploratory pit borehole 729d are situated in the block marked as II, forming a downthrow side, whereas the pit boreholes CH2 and CH3 in the block marked as III forming a hanging fault-wall.

The structural and tectogenetic analysis of the coal-mine coal-bearing series has indicated that the faults are primarily of tension nature. The above statement has a practical meaning. It can imply that deposit penetration by all kinds of waters is greatly facilitated in predominating geological and structural tension conditions.

HYDROGEOLOGIC CONDITIONS

The Upper Carboniferous formations deformed with numerous faults dip gently to the south, under the cover of Miocene and Triassic formations. The Carboniferous strata inclination forms favourable conditions for atmospheric waters infiltrating in the strata outcrop area to flow into deeper parts of the orogen.

WATER-BEARING HORIZONS IN THE OVERLAY

The following formations were discerned within the Carboniferous overlay strata:

Quaternary water-bearing horizon. The Quaternary formations are supplied through the infiltration of atmospheric precipitation. The water level is stabilised at the depth of 1.54 to 5.85 m. The filtration coefficient for impermeable sediments of that water-bearing horizon varies between 1.50 x 10^{-5} m/s to 2.30 x 10^{-4} m/s.

Triassic water-bearing horizon is related to dolomites and limestones of shell limestone as well as Raethian sandstones. The thickness of this formation in the coal-mine area ranges from 100 m in the west to 200 m in the east.

The water level is stabilised at the depth of 29.0 to 43.1 m. The carbonate series is supplied with atmospheric precipitation waters. The calculated average filtration coefficient for the Triassic water-bearing horizon in the coal-mine area ranges from 1.90 x 10^{-4} to 3.80 x 10^{-6} m/s.

CARBONIFEROUS WATER-BEARING HORIZON

This horizon is related to permeable Carboniferous formations, i.e. the sandstone bed of Cracow sandstone series (KSP), mudstone series (SM) and the Upper-Silesian sandstone series (GSP) - absorptive strata. The insulation strata are clay-stones and mudstones accompanying coal beds. The package isolating KSP sandstones from GSP sandstones - absorptive strata is the mudstone series (SM) developed in the form of clay-stones and mudstones 400-600 m thick. The water-bearing standstones are supplied at their outcrops and also through Triassic rocks and Quaternary deposits in the regions where there are no isolating impermeable deposits or where their continuity has been disrupted by orogen deformations caused by mining exploitation. The Carboniferous orogen includes joints, fissures, faults and stratification planes, which cause the rock core anisotropy and as a result the hydraulic conductivity of the rock massif is higher than filtering and storage properties of sandstones.

Cracow sandstone series

Cracow sandstone series of the thickness up to 700 m is represented in 90% by sandstones. It makes the main Carboniferous water-bearing horizon. The filtration coefficient for Cracow sandstone series above the depth of 200 m is ca 1 x 10^{-5} m/s and below that depth it decreases to ca 4 x 10^{-7} m/s.

Mudstone series

The mudstone series (SM) reveals the thickness of 400 to 600 m. Its profile is dominated by mudstones and clay-stones. Sandstones occur on a limited scale. Generally, mudstone series strata may be treated as a thick insulating series of very low vertical permeability.

Upper-Silesian sandstone series - protective strata

Absorptive strata of the thickness up to 140 m are predominantly composed of sandstones with thin interbeddings of clayey rock. Sandstones occurring in the absorptive strata are characterised by: regular spreading, high filtration, considerable thickness and high porosity. The above facts confirm the usefulness of sandstones occurring in absorptive strata for compressing in salt waters. The protective strata sandstone filtration coefficient varies between above 1 x 10^{-5} m/s to below 1 x 10^{-7} m/s. The average open porosity coefficient for absorptive strata sandstone in the compressing borehole areas ranges from 18 to 24%.

COMPRESSING BOREHOLE CHARACTERISTICS

The standard construction of a surface absorptive borehole was adopted for pit boreholes. The drilling technology applicable in pit conditions resulted in restriction on the drilling diameter, which determined the designed diameter of the injection duct. The compressing boreholes were drilled until it was established that protective layers had been drilled through and border layer formations had been bored.

Borehole CH-1 - surface

The borehole was drilled to the depth of 998 m, with coreless drilling to the depth of 500 m below the terrain level and further below - with the core recovery. The ending diameter Ø 12 1/4".

Borehole CH-2

The borehole final depth is 380.0 m. The borehole was drilled with full coring. The ending diameter Ø 93 mm.

Boreholes CH-3

The borehole ending depth is 430.7 m. The borehole was drilled with full coring. The diameter is Ø 93 mm.

GEOLOGIC EXAMINATION RESULTS

The Upper-Silesian sandstone series - absorptive strata have been drilled through with all boreholes.

Due to the destination and technological assumption of planned installation, the protective layers include not only the sandstones of the Upper-Silesian sandstone series but also those present under the conglomerate layer which is the stratigraphic border of those layers.

The thickness of thus separated Upper-Silesian sandstone series - absorptive strata amounts in respective boreholes to:

CH-1 = 104.80 m
CH-2 = 136.25 m
CH-3 = 100.15 m

The sandstone beds are considerably cracked flatwise, while the deepest crack network is in sandstones from the CH-2 borehole. So called sandstone "disking" occurs here, which leads to dividing of the sandstone into individual layers 1-2 cm thick (Figure 2). From the point of view of future appropriation of the boreholes, this feature is very advantageous, as it has a beneficial effect on filtration properties of the rock layers that are present within the absorptive strata.

The table below presents the percentage share of individual lithological separations in the absorptive strata profile.

CH-1		CH-2		CH-3		
(M)	(%)	(M)	(%)	(M)	(%)	
10.25	10.97	4.70	4.87	12.40	12.38	Clay-stones
8.50	9.92	1.50	1.55	4.80	4.79	Mudstones
66.30	73.40	87.75	90.93	79.20	79.08	Sandstones

RESULTS OF HYDROGEOLOGICAL INVESTIGATIONS IN BOREHOLES

Six water-bearing layers have been singled-out from the floor of the Upper Silesian sandstone series in profiles of absorptive boreholes. The water-bearing layers IV, V and VI were singled out on the basis of direct observation of the borehole core obtained during drilling and of pressure and water quantities flowing out from the borehole.

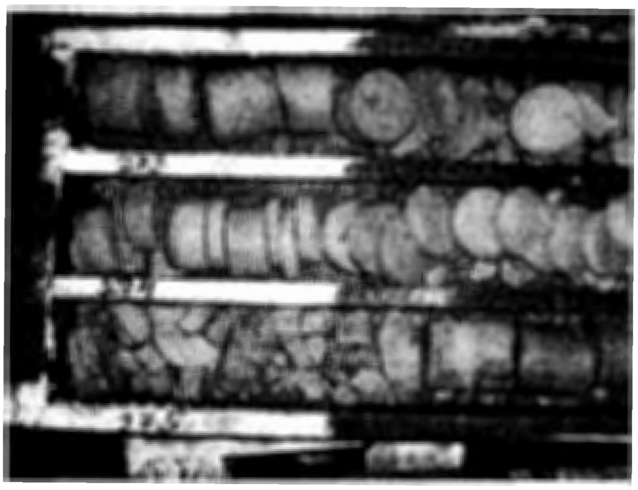


Figure 2. "Disk" type sandstones of absorptive layers from borehole CH-3

Borehole CH-1

A hydrogeological field investigation for determining the filtration coefficient by the borehole flooding method was conducted for rock layers connected with the Upper-Silesian sandstone series, on the section where perforated pipes had been mounted (880.0-955.0 m).

Based on results obtained the average value of filtration coefficient was calculated for the examined section of rock layers ($k = 1.42x10^{-7}$ m/s).

Duration of measurements - 71 hours.

Moreover, the size of the filtration co-efficient for the assumed 12-hour intervals of the fall of water column in the borehole was calculated.

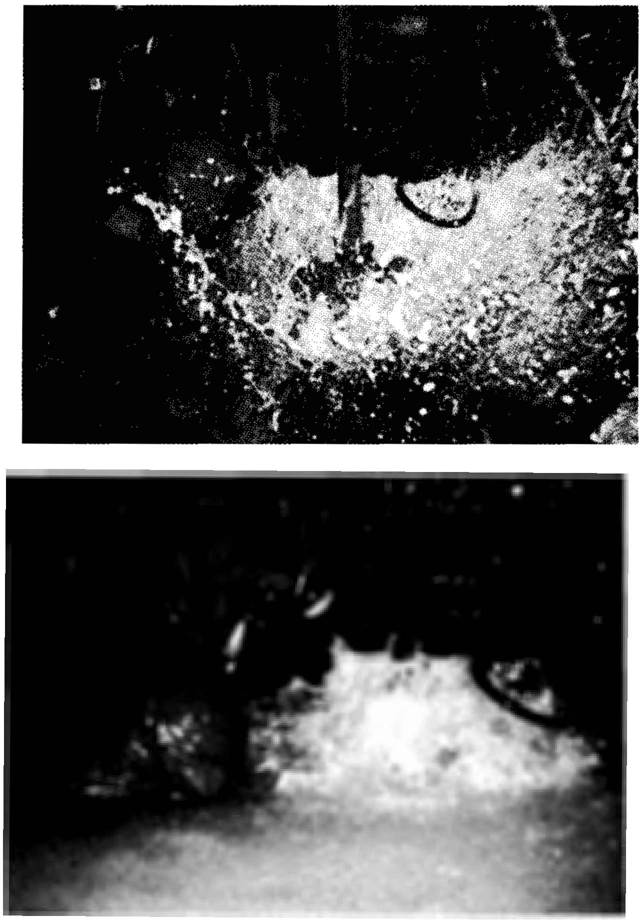
Furthermore, basic hydrogeological parameters of rock layers in the examined profile section, with porosity from 11.15 to 21.33 % and filtration coefficient of 3.42E-10 - 1.96E-5 were determined for the foregoing Carboniferous stage interval.

Borehole CH-2

Two water-bearing layers were determined in the drilled through Carboniferous stage interval. After drilling through the absorptive layers the self-outflow from the borehole amounted to 2800 dm^3/min, whereas the pressure at the mouth stabilised itself on the level of 2.3mpa (see Figures 3 and 4).

The water-bearing level of the Upper Silesian sandstone series consists of two water-bearing layers (V and VI).

V water-bearing layer. Sandstones are heavily cracked with so called disking of the sandstone core (division into layers in conformity with the bedding), up to 2 cm thick. The thickness of stratum in the place of drilling amounts to M = 50.35 m. The filtration coefficient of formations making up the fifth water-bearing layer, calculated on the basis of conducted hydrogeological field investigations, amounts to $8.01x10^{-7}$ m/s. The stabilised inflow of water from the stratum amounts to Q = 100 dm^3 m/min. The calculated pressure of deposit reaches up to P_z = 4.6 Mpa whereas pressure measured at the head of the borehole amounts to P_g = 2.0 Mpa.



Figures 3 and 4.

VI water-bearing layer. The formations are of medium compactness, cracked, locally washed out and porous. Thickness of the layer in place of drilling is M = 21.30 m. The filtration coefficient of formations making up the sixth water-bearing layer amounts to $k = 5.88x10^{-6}$ m/s. The inflow of water has stabilised itself on the level of Q = 1500 dm^3/min, whereas calculated deposit pressure reached up to P_z = 6.6 Mpa and pressure measured at the head of the borehole amounted to P_g = 2.3 Mpa. Whilst enlarging the borehole to 93 mm diameter there was an increased inflow of water from Q = 1500 dm^3/min to Q = 2800dm^3/min. Another series of hydrodynamic measurements was carried out at increased inflow to determine the filtration coefficient for layers V and VI together. This value amounted to $k = 2.86 - 4.24 \times 10^{-6}$ m/s.

Furthermore, porosity in the range from 12.29 - 21.24 % and filtration coefficient 4.02E-10 - 3.26E-5 were determined for the foregoing Carboniferous stage interval.

Borehole CH-3

In the drilled through Carboniferous stage interval two water-bearing levels were marked out, where the second one, consisting of two layers (V, VI) was stratigraphically connected with the Upper-Silesian sandstone series. After drilling through the absorptive layers the self-outflow from the borehole amounted to 2300 dm³/min, whereas the pressure at the borehole mouth had stabilised itself on the level of 2.9 Mpa.

The self-outflow after sinking the Ø 44.5 mm injection pipe and packer with inside diameter of Ø 24 mm was reduced to 300 dm³/min, whereas pressure at the borehole mouth had stabilised itself on the level of 2.7 Mpa.

IV water-bearing layer/absorptive layer is built of very cracked porous rock. Thickness of layer in place of drilling is M = 14.55 m. It was bored in the interval 221.00 - 235.55 m. The filtration coefficient of sandstones making up the fourth water-bearing layer, calculated on the basis of hydrogeological field investigations, amounts to k = 3.41x10^{-6} m/s. Stabilised inflow from the layer is Q = 100 dm³/min, calculated deposit pressure is P_z = 3.70 Mpa, whereas pressure measured at the mouth of the borehole P_g = 1.5 Mpa.

V water-bearing layer consists of medium and coarse-grain sandstone with conglomerate inserts. Sandstone is moderately coherent, porous, slightly cracked. Thickness of water-bearing layer in place of drilling is M = 5.20 m, this layer being bored in the interval 254.70 - 259.50 m. Filtration coefficient of sandstone making up the fifth water-bearing layer, calculated on the basis of hydrogeological field investigations, amounts to k = 2.59x10^{-7} m/s. The stabilised inflow from the stratum amounted to Q = 20 dm³/min. Calculated deposit pressure reaches P_z = 2.75 Mpa, whereas pressure measured at the mouth of the borehole is P_g - 0.2 Mpa.

VI water-bearing layer. Rock formations making up the water-bearing layer are of moderately coherent, porous or with fissures and cracks. Thickness of water-bearing layer in place of drilling amounts to M = 53.75 m, this layer being bored in the interval 267.40 - 321.15 m. Filtration coefficient of sandstone making up the sixth water-bearing layer, calculated on the basis of hydrogeological field investigations, amounts to k = 3.73x10^{-6} m/s. The stabilised inflow from the stratum amounted to Q = 2300 dm³/min. Calculated deposit pressure reached P_z = 5.5 Mpa, whereas pressure measured at the mouth of the borehole was P_g - 2.9 Mpa.

CHEMICAL COMPOSITION OF WATERS

Mineralization of waters in SM layers changes in the range from 1.4 -247.6 g/dm³ in the CH-2 borehole to 9.9 - 189.9 g/dm³ in CH-3 borehole. Mineralization of water in absorptive layers of Upper Silesian sandstone series changes in the range from 177.2 - 232.2 g/dm³ in CH-2 borehole to 200.6 - 217.5 g/dm³ in CH-3 borehole. Based on results of chemical analyses of water from boreholes CH-1, CH-2 and CH-3 it was found that mineralization of water increases stepwise with depth, thus confirming **distinct vertical hydrochemical zonality** and lack of direct hydraulic contact between particular water-bearing layers in the bored interval of SM and GSP levels of the absorptive layers.

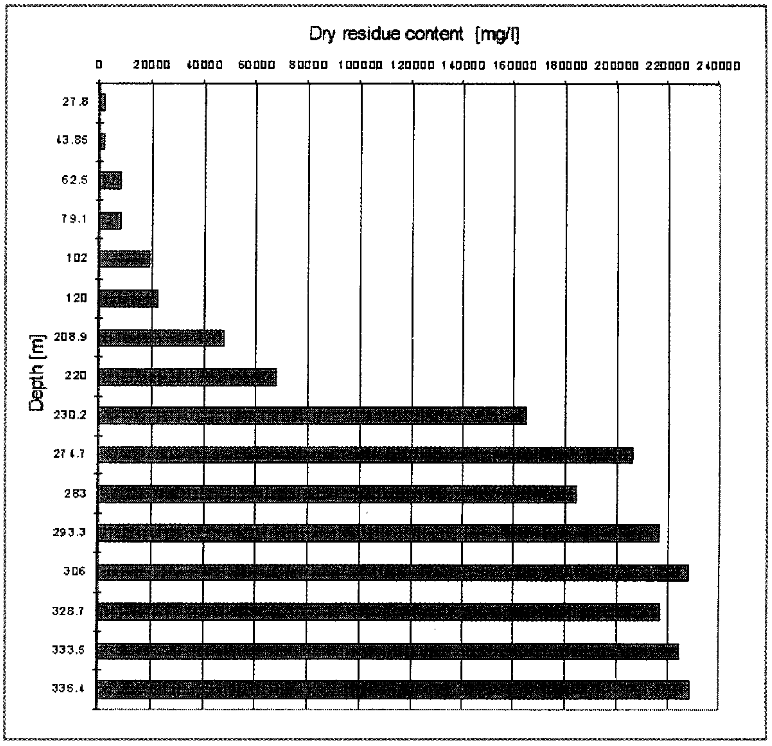


Figure 5. Diagram of dry residue in water flowing out from the borehole CH-2.

Stepwise changes in general mineralization of waters in those strata are the proof of that. The singled out zone of fresh water extended to water with mineralization up to 2g/dm³, was found in No. 1 drilled water-bearing layer in CH-2 borehole.

The middle (transitional) zone, containing water with mineralization up to 10 g/dm³, was found in No. 2 drilled water-bearing layer in CH-2 borehole and in No. 1 water-bearing layer in CH-3 borehole.

The water-bearing layers drilled at a lower level are in the mineral water zone, where mineralization increases with depth. The vertical hydrochemical zonality of water is a reflection of the current (disturbed) condition, directly influenced by mining conducted in the past and at present, connected with underground water drainage and pumping out.

MINE SALT WATER PILOT PUMPING SYSTEM

Based on studies and analyses of the possibilities of pumping salt water into absorptive layers, as conducted at the design stage, it was assumed that:

- absorptive power of the borehole is 800 dm³/min
- pumping pressure at borehole mouth - 5.2 -6.5 Mpa

It is a pilot system due to its location in the area of underground working and the nature of pumping (trial pumping). Location in underground working areas allowed to shorten the distance of sending the water to the ground during pumping tests. Water collected in the underground heading flows down to the injection chambers under force of gravitation, without costly pumping to the surface. The pilot nature also pertains to parts of the installation responsible for water conditioning. Preliminary results show that it is necessary to extend the system by installing conditioning units and changing cross-sections of certain elements of the pumping system.

Water designed for pumping into the GSP is taken from blocked off abandoned workings in bed 209, C lot, forming a storage reservoir with capacity of approximately 450 thousand m^3.

Water is supplied through Ø 150 mm PVC pipes to two cleaning filters of 1st stage and then to two filters of 2nd stage cleaning. The body of 1st and 2nd stage cleaning filters is made of welded stainless steel. Filter types, elements and their parameters have been designed based on granulometric test of suspended matter in underground waters of Jaworzno Mine. From filters, which form the second cleaning stage, water is sent to a storage tank with overall dimensions 4500 x 1100 x 1950 mm. The tank is made of PVC and is fitted with a water-gauge and DN 50 drain. From the tank water flows by gravity through a 150 mm diameter PVC pipeline to three type 40-PCD-5-60 plunger pumps, with maximum compression of 16 Mpa. Each of the openings is fitted with three force pumps with rated output of 380 dm^3/min each.

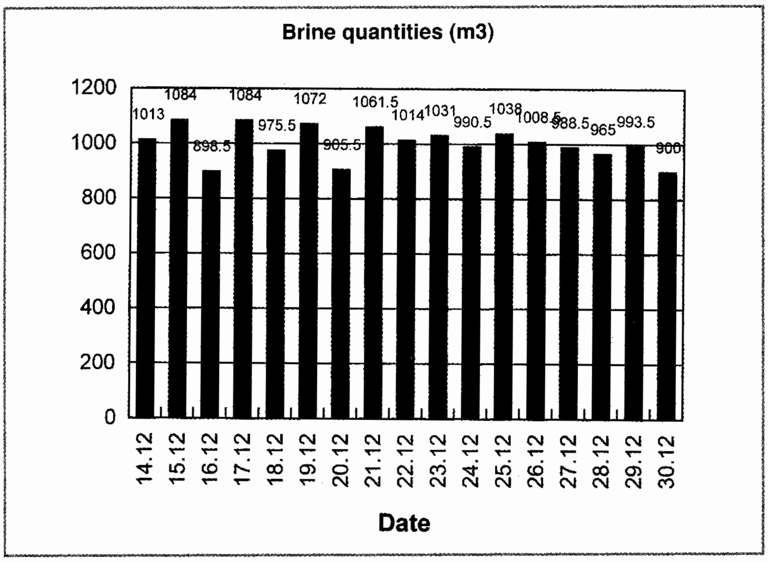


Figure 6. Diagram of brine quantities pumped into the borehole CH-2 during 24 hours.

Two of three pumps, which have been installed on the pumping opening, operate continuously, whereas the third is in stand-by. From the pumps water is forced through Ø 32 mm high-pressure hoses to absorptive layers through the head and injection conduit. The injection head, made of stainless steel, has been fitted on the outlet with a glycerine manometer with measurement range up to 15 Mpa.

Pumped water has been tested for its conformity with bed water within the absorptive layers area.

Water designed for pumping is cleaned on two-stage pressure filters manufactured by Bool & Kirch. The first, so called preliminary stage of cleaning, takes place on filter elements capturing particles bigger than 10 μm in diameter. Filters which form the second stage of cleaning are used to separate solid phase particles bigger than 3 μm in diameter from water.

Based on granulometric analysis of matter suspended in water taken from behind the barrage TW-44, the efficiency of filters was assessed to be 99.3% (accuracy of removing suspended matter from water supplied from behind the barrage). The conducted pumping trials confirm the absorptive power of the layer, assumed at the design stage, allowing the injection of 750-800 dm^3/min brine to each hole. As results from the trials two working pumps are sufficient for obtaining such delivery of pump in conformity with the assumptions. As results from pumping to boreholes CH-2 and CH-3, pumping pressure measured during injection trials at the mouth of the borehole CH-2, with a maximum value of 6.5 Mpa, can be obtained in the CH-3 borehole. This however requires the correction of CH-3 borehole design (removal of injection pipe with packer) with the purpose of reducing pressure losses during the flow of brine. Also the correction of chemism in pumped water is required (elimination of iron, pH correction) to eliminate the precipitation of iron compounds in filtered water.