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REHABILITATION AND REPAIR OF METAL DISCHARGE PIPELINES OF AMU-ZANG 2 PUMP STATION BY MEANS OF SHOTCRETING WITH KALMATRON® KF-A

December 2nd, 2010

1. INTRODUCTION

According to the report results of "DETERMINATION OF RESIDUAL SEVICE LIFE OF DISCHARGE PIPELINE OF AMU-ZANG 2 PUMP STATION" and results of "WATER HAMMER ANALYSIS", we propose to carry out rehabilitation works of discharge pipeline by means of internal shotcreting with PLASTCRETE mortar.

Shotcreting efficiency with PLASTCRETE mortar, developed by our company, for applications on the surfaces made from stone, concrete, metals and polymers, has been tested over the last 12 years on the structures of water supply, sewage, chemical and agricultural industries. This mix design, with allowable W/C ratio of 0.38-0.43, contains an additive KALMATRON® KF-A, which is designed to ensure a complete hydration of cement with the subsequent hardening into a solid cement stone, which does not have secondary reaction products with water or corrosive environment (design mix is provided). Therefore, there are no "sources" for corrosion (see Appendix KF-A for concrete, HPC).

According to ASTM C 494: "Standard specifications for chemical additives to concretes" additive KALMATRON® KF-A and its liquid version K100 belongs to two types:

1. Type C – cement hydration accelerator and
2. Type F – water-reducing, fine grained, functioning as an inorganic oxidizer of micro/macro elements containing in cement products that increases the aggregate surface of cement gel. For example: measured that in 20 minutes after adding the additive into concrete mix, the size of cement "grain" has decreased from 96μ to 10μ.

Oxidizer reactions with metal elements allow to reach a stable chemical adhesion of cement paste that is applied on metals or on materials containing metals and/or products of its oxidation. The largest volume of rehabilitation and repair works of metal aqueduct is being carried out in Mojave Desert. The aqueduct was build more than 50 years ago, aqueduct's pipe metal lost up to 20% of its thickness due to erosion and electrochemical corrosion as well (see www.shieldcrete.com > PLASTCRETE).

Fig. 1 Internal surface of aqueduct's metal pipe after shotcreting with PLASTCRETE mortar

Fig 2. Metal aqueduct ≈ ∅ 3.5 m and length of 129 km (80 miles) experiences salient water hammers up to 50 bars. Shotcreting works are being continued.

2. INITIAL DATA[1]

Table 1 - Monthly temperature in city of Termez, Uzbekistan

Name of parameters Termez 37 23 N, 67 26 E, 302 meters above sea level	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature	4	6	11	18	25	29	30	28	22	16	10	6
Average maximum temperature	11	13	17	26	33	38	40	38	32	25	18	13
Average minimum temperature	0	0	5	11	16	19	21	18	12	8	3	0
Average rain days	3	3	6	3	1	0	0	0	0	1	3	2
Average snow days	2	2	1	0	0	0	0	0	0	0	0	1

2.2. Metal low carbon pipes ∅ 2240 mm and ∅ 3240 mm with length of 520 m, where:

ρ_1 = 7850 [kg/m^3] - metal density;
α_1 = 11.7 [10^{-6} m/m°C] - coefficient of thermal expansion;
λ_1 = 16 [W/m°C] - coefficient of thermal conductivity;
$E_1 = 2 \times 10^5$ MPa = 2×10^6 kg/cm^2 = 2 x 10 kg/mm^2- Young modulus;
V_1 = 0.27 Poisson ratio;
$s_1 \approx 12$ mm – pipe wall thickness

2.2. Shotcrete PLASTCRETE is cement-sand mix design with additive KALMATRON KF-A

ρ_2 = 1800 [kg/m^3] PLASTCRETE density;
α_2 = 14.5 [10^{-6} m/m°C] coefficient of linear thermal expansion;
λ_2 =1.73 [W/m °C] coefficient of thermal conductivity;
$E_2 = 3 \times 10^4$ MPa = 3×10^4 kg/mm^2=30 kg/mm^2 - Young modulus;
v_2 = 0.107967 Poisson ratio;
$s_2 \approx 20$ [mm] – PLASCRETE shotcrete thickness

3. THERMOMECHANICAL COMPATIBILITY OF PLASTCRETE LAYER AND METAL PIPE

Thermomechanical compatibility of actual pipe materials and shotcrete and joint works of the applied shotcrete on the internal surface of metal pipe are being considered within annual cycle of outside air temperature.

3.1. CHANGE OF CIRCUMFERENCE LENGTH OF METAL PIPE AND CYLINDRYCAL SHOTCRETE BODY DURING ANNUAL AND DAILY TEMPERATUES

The shotcrete layer thickness shall be considered satisfactory when the temperature deformation of this layer and metal pipe reaches the minimum difference in the cycle of annual temperatures, and as well as in extreme months during a year. The change of circumference length “dc” of shotcrete layer and metal pipe is calculated by using equation (1), where the temperature difference “dT” is taken between subsequent and previous date.

The size of radius “r_0” is taken without the shotcrete layer thickness, its change has impact on the thermal elongation or shortening of circumference lengths and also on all subsequent results.

$$\mathbf{dc = c_1 - c_0 = 2\,\pi \bullet r_0 \bullet dt \bullet \alpha,} \qquad (1)$$

[1] www.weather .com and www.pogoda.ru.net

dc = change of circumference length (m)
c_1 = final circumference length (m)
dt = change of temperature (^oC)
α = coefficient of linear thermal expansion (mm/m ^oC)

Table 2 - Calculation of thermal deformations of circumference lengths of metal pipe and PLASTCRETE shotcrete – 20 mm under average stable temperature conditions within a year

Name of parameters	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Averaged annual temperatures	4	6	11	18	25	29	30	28	22	16	10	6
dc, mm, Metal pipe	0.16	0.16	0.17	0.74	0.58	0.41	0.58	0.49	0.58	0.57	0.41	0.16
dc, mm, PLASTCRETE shotcrete	0.20	0.40	0.90	0.70	0.50	0.20	0.20	0.60	0.70	0.50	0.70	0.50
The difference of thermal expansions and compressions, mm	-0.04	-0.24	-0.73	0.04	0.08	0.21	0.38	-0.11	-0.12	0.07	-0.29	-0.34

Due to a high crystalline component of PLASTCRETE matured layer, its coefficient of linear thermal expansion can be higher than the same coefficient in some metals that determines its high thermomechanical properties.

Table 3- Calculation of thermal deformations of circumference lengths of metal pipe and PLASTCRETE shotcrete – 20 mm under average stable temperature conditions during winter and summer periods

Name of parameters	**Months**											
	January						**July**					
Time of day, hour	8	11	14	17	20	24	8	11	14	17	20	24
Temperature, °C	-21	-14	-10	-18	-20	-24	20	33	45	38	26	19
dc, mm, Metal pipe	0.57	0.33	0.17	0.66	0.16	0.32	1.07	0.99	0.58	0.57	0.99	0.57
dc, mm, PLASTCRETE shotcrete	0.70	0.40	0.80	0.20	0.40	0.25	1.30	1.20	0.70	1.20	0.70	0.10
The difference of thermal expansions and compressions, mm	-0.13	-0.07	-0.63	0.46	-0.24	0.07	-0.23	-0.21	-0.12	-0.63	0.29	0.47

In tables 2 and 3 as follows from the difference of thermal expansions and compressions, the circumference lengths change of pipe and shotcrete occurs with a delay of the latter. This results in deformations of shotcrete layer compression by a metal pipe along the lengths of its circumferences under the change of annual and daily temperatures.

3.2. ASSESSMENT OF SHOTCRETE THICKNESS UNDER CONDITION OF THERMOMECHANICAL COMPATIBILITY WITH METAL PIPE

Shotcrete layer thickness on the internal surface of metal pipe shall satisfy the condition of thermomechanical balance, when possible movements of contact area between internal pipe wall and applied shotcrete create stresses below the resistance for expansion of shotcrete material.

3.3. CALCULATION OF TEMPREATURE STRESSES OF METAL PIPE AND PLASTCRETE SHOTCRETE– 20 mm

During heating or cooling of metal pipe and ring cross-section of shotcrete layer along its circumference length, the stresses delivered on shotcrete surface are determined by equation (2):

$$\boldsymbol{\sigma_2 = \frac{E_2 \cdot \alpha_2 \cdot dT}{2(1 - \upsilon_2^2)} (Cx + \upsilon_2 \cdot Cy)} \qquad (2)$$

where:
σ_2 – maximum stress on shotcrete layer surface;
α_2 = 14.5 [10^{-6} m/m°C] coefficient of linear thermal expansion;
$E_2 = 3 \times 10^4$ MPa = 30 kg/mm^2 Young modulus;
v_2 = 0.107967 Poission ratio for cement mix design;
dT – difference in temperatures in hours and days;
Cx = 0.8 coefficient of contact stabilization between the internal pipe surface and external shotcrete surface, horizontally.
Cy = 0.65 coefficient of contact stabilization between the internal pipe surface and external shotcrete surface, vertically.

Evidently, equation (2) is practically applicable for the assessment of stresses in the period of stable daily temperatures, when the change of radius lengths and, accordingly, shotcrete thicknesses and the lengths of its circumference occurs simultaneously on the entire surface.

The solution of isotropic problem completely describes structure’s behavior and allowed to obtain practical assessment results of thickness sufficiency of shotcrete layer and its resistance to thermomechanical stresses transferred by a metal pipe. Shotcrete layer thickness of 20 mm is the most satisfactory thickness. The results are shown in Tables 4 and 5.

It shall be noted that for an independent shotcrete operation as a cement pipe inside a metal pipeline, the required thickness of ring cross-section shall be 40 mm.

Table 4 – Calculation of thermal stresses of metal pipe and PLASTCRETE shotcrete – 20 mm under average stable temperature conditions during winter period

Name of parameters	**Month**					
	January					
Time of day, hour	8	11	14	17	20	24
Temperature, °**C**	-21	-14	-10	-18	-20	-24
dc, mm, Metal pipe	0.57	0.33	0.17	0.66	0.16	0.32
dc, mm, PLASTCRETE shotcrete	0.70	0.40	0.80	0.20	0.40	0.25
The difference of thermal expansions and compressions, mm	-0.13	-0.07	-0.63	0.46	-0.24	0.07
Stresses on shotcrete layer, σ_2 [MPa]	-0.57	1.34	0.76	-1.53	0.38	0.76

Table 5 - Calculation of thermal stresses of metal pipe and PLASTCRETE shotcrete – 20 mm under average stable temperature conditions during summer period

Name of parameters	**Month**					
	July					
Time of day, hour	8	11	14	17	20	24
Temperature, °**C**	20	33	45	38	26	19
dc, mm, Metal pipe	1.07	0.99	0.58	0.57	0.99	0.57
dc, mm, PLASTCRETE shotcrete	1.30	1.20	0.70	1.20	0.70	0.10
The difference of thermal expansions and compressions, mm	-0.23	-0.21	-0.12	-0.63	0.29	0.47
Stresses on shotcrete layer, σ2 [MPa]	-0.19	2.48	2.29	-1.34	-2.29	-1.34

Depending on water-cement ratio of PLASTCRETE preparation, its strength characteristics are determined as following:

- Prismatic compressive strength from 41 MPa to 50 MPa; [2]
- Axial tension from 7.5 MPa to 12 MPa. [2]

Stresses on shotcrete layer from compression and tension are considerably lower than PLASTCRETE strength indicators [2]. Therefore, joint thermomechanical work of metal pipe and ring cross-section of shotcrete allows not to depend on its plastic properties.

Hydraulic loads from vacuum - 6 bars to 10 bars [1] are perceived by transferring from shotcrete layer onto the internal wall of metal pipe. Proven the abovementioned joint work of shotcrete with thickness of 20 mm with the pipe provides significantly higher resistance to water hammers due to the increased pipe section and its weight. In places of pipeline diameter changes and its abutments to nodal devices, a smooth transition of shotcrete layer thickness shall be ensured.

The distribution of axial vibration on the increased pipeline section will decrease or eliminate excessive load on movable supports on separate pipeline sectors. The restoration of roller supports ensures their hinged mechanism of water hammer amortization.

We have experience of applying PLASTCRETE shotcrete inside a pipe, where metal bottom has exhausted its operational thickness by abrasive water flow. On these sectors, all pipeline loads are taken by the shotcrete layer as an independent pipe.

The protection of expansion bends of metal pipeline is proposed to carry out inside by PLASTCRETE shotcrete, as well as in the main pipeline, where straight sectors of expansion bends shall be covered outside by thermal insulation mix KALMATRON KF-I with thickness of 30 mm for the reduction of deformations against sun heating. Turning or edged sectors shall be left opened; however, they shall be painted outside by a white oil paint in two coats in order to reduce sun heating of metal pipe up to 10%.

4. EXTREME CONDITIONS OF COMPATIBILITY OF PLASTCRETE AND METAL PIPE

It has been suggested to consider an empty pipeline under a long-term temperature of -30°C that occurs during winter night time, as stated in Table 6. Since cooling occurs simultaneously along the entire pipeline surface, the calculations were performed based on equations (1) and (2).

Table 6 – Calculation of thermal stresses of metal pipe and PLASTCRETE shotcrete – 20 mm under extreme temperature conditions during winter period

Name of indicators	**Month**					
	January					
Time of day, hour	20	22	24	2	4	6
Temperature, °**C**	-21	-16	-30	-30	-28	-24
dc, mm, Metal pipe	-0.247	-0.412	-0.329	0	0.165	0.329
dc, mm, PLASTCRETE shotcrete	-0.306	-0.509	-0.408	0	0.204	0.408
The difference of thermal expansions and compressions, mm	0.059	0.097	0.079	0	-0.039	-0.079
Stresses on shotcrete layer, σ_2 [MPa]	-0.579	-0.955	-0.764	0	0.382	0.764

According to the results in Table 6, neither deformations nor stresses cause critical magnitudes. In stabilizing mode of -30°C, deformations and stresses are uniform for pipes and for PLASTCRETE as well, and equaled to “0”.

Also, suggested to consider an empty pipeline under heating by sun up to 90°C that occurs during a summer day. In this case, pipeline is heated not entirely, but along the length of a movement of heat ray. The most dangerous condition is heating of a pipe surface pipe, when reactive stresses emerge with a non-heated surface.

In extreme heating conditions of a pipe surface part by sun, the fourth part of pipe circumference length is considered as the most possible lighted and heated part from one position (see Fig. 3).

Stresses σ_2 directed along a normal line in conditions (2), in case of partial heating, pipe surfaces undergo a directional change of corresponded angle “i” between normal line and increased radius length in the heated sector.

On Fig. 3, a diagram of contact zone line change between metal pipe and shotcrete layer during heating by sun in upper left sector is shown, where the heated part is highlighted with red. Circumference radius $\mathbf{r_i}$ corresponds to internal pipe radius, which is also external radius of shotcrete layer. Radius $\mathbf{r_{i+n}}$ is variable in points **b', c', d'**, which is equaled to radius $\mathbf{r_i}$ in points **a** and **e.**

In points **b** and **c’**, the line deflection of contact zone with transition to the other circumference from radius $\mathbf{r_i}$ to radius $\mathbf{r_{i+n}}$ is shown, both radii have own tangential lines indicated by dotted lines, the crossing of which create the angle “i”. This angle is a characteristic of a delay of shotcrete layer thermal expansion from metal pipe wall expansion and stress indicator of section condition.

Stressed section condition is calculated according to Hooke’s law of elastic potential energy, where the change of anisotropic material area realizes into force dN, causing stress $d\boldsymbol{\sigma_2}$, directed to the side, where section change occurs:

$$\mathbf{d\sigma_2 = dN/\ 0.25\ A_{wall}\ ;} \qquad (3)$$

$$\mathbf{dN = E_2\ x\ dA\ x\ dC_{arc}\ /C;} \qquad (4)$$

$$\mathbf{dN = E_2\ x\ dA\ x\ dC_{arc}\ /C = E_2\ x\ \int dA\ x \int dC_{arc}\ /C;} \qquad (5)$$

$$\mathbf{N_i = E_2\ x\ A_{arc}\ x\ ln\ [C_{arc} - C_{cir}]\ ;}\ [Kg] \qquad (6)$$

where:

l = ac = 0.0177 [m]; l' = ac' = 0.01786 [m]; L = ae = 0.0301 [m] (see Fig. 3);

$\mathbf{A_{cir} = 0.5\ r_i\ x\ L\ x\ h = 0.5\ x\ 1.12\ x\ 0.0301\ x\ 0.02 = 3.37\ x\ 10^{-4}}$, [m^2] – arc area before deformation

$\mathbf{A_{arc} = 0.5\ r_{i+n} \int dC_{arc}}$; [$m^2$] – area of PLASTCRETE deformed arc **a,b’,c’,d’,e** (see Table 7).

$\mathbf{C_{cir} = 2l + 1/3(2l - L) = 2\ x\ 0.0177 + 1/3\ (2\ x\ 0.0177 - 0.0301) = 0.03717,}$ [m]; – design arc length based on Huygens law.

$\mathbf{C_{arc} = C_{cir}\ x\ cos\ i = 2l’ + 1/3(2l’ - L),}$ [m]; **–** deformed arc length (see Table 7).

The distribution of value N from 0 in point “a” to maximum value in point “c^1” corresponds to thermal length changes of radius r_i, that realizes into normal stresses with a change of angle “i”. Corresponding to the radius direction and depending on the value of its thermal change, this force is a concentrated radial pressure N. As noted, we consider ¼ of lateral pipe part, faced to sun movement from 8:00 to 12:00, as stated in Table 7 and Fig. 3 from point “a” to point “d”.

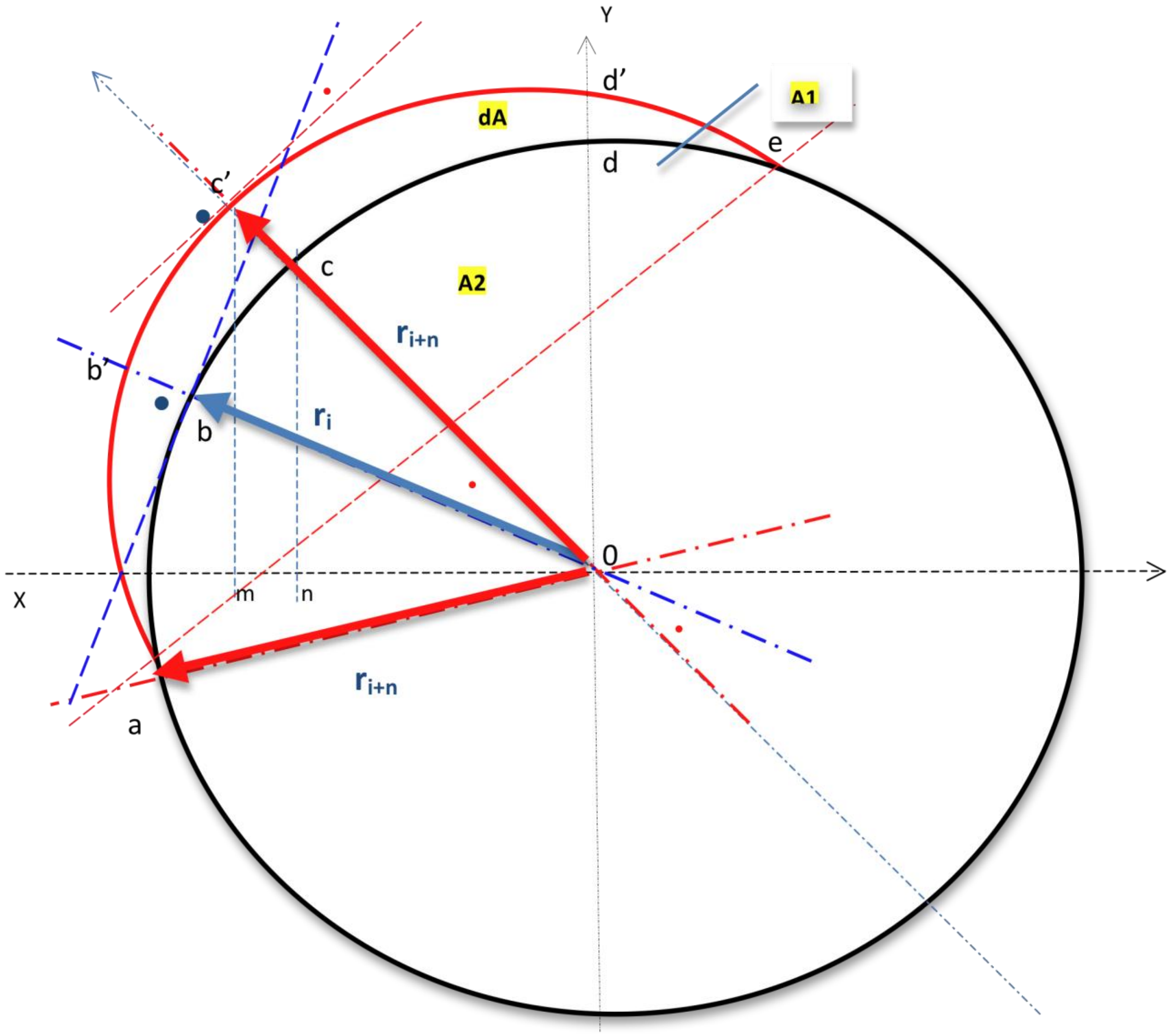

Fig. 3 - Diagram of temperature deformations of contact zone between pipe and shotcrete layer in upper left sector, where pipe surface area heated by sun is shown with red color

● - angle 90°

• - angle “i” between tangent lines to pipe surface and its deformed contour and between the radii as normal lines to which these tangent lines are built

A_{tor}; = $\pi(R_i^2 - r_i^2)$ = 3.14 ($1.12^2 - 1.1^2$) = 0.138 (m^2); - design area of PLASTCRETE section.

$A_{wall} = 2\pi \times r_{i+n} \times l = 2 \times 3.14 \times 1.12 = 7.034$ (m^2) in case with $r_i = r_{i+n}$ – area of PLASTCRETE lateral surface

Each unknown assessment value of “Pipe-PLASTCRETE” thermomechanism is real in definitive day time of July during a movement of heat ray along the pipe surface (Fig. 3). Length changes of radius r_{i+n}, length of arc C_{arc} and areas of deformed PLASTCRETE part A_{arc} are given in Table 7.

Table 7 – Calculation of thermal deformations of PLASTCRETE shotcrete – 20 mm under extreme temperature conditions in summer

Name of indicators	Month					
	July					
Time of day, hour	8	10	12	14	16	18
Temperature, °C	40	60	90	90	80	60
r_{I+n}, Deformed arc radius (mm)	1120.33	1120.33	1120.9	1120	1119.83	1119.68
C_{arc}, Deformed arch length, (m), (a, b', c', d', e)	0.0372	0.03896	0.04125	0.04154	0.04148	0.04140
A_{arc}, Deformed PLASTCRETE sector area, m^2, (a, b', c', d', e)	$5.56x10^{-6}$	$5.88x10^{-6}$	$5.96x10^{-6}$	$6.1x10^{-6}$	$5.99x10^{-6}$	$5.87x10^{-6}$
N, Radial pressure causing by deformation (kg/linear meter)	-173472	-176643	-179571	-182473	-178999	-177662
Stresses on shotcrete layer, σ_2 [MPa]	-0.986	- 1.004	- 1.0203	- 1.0368	- 1.01699	- 1.00944

Therefore, in summer period of operation, PLASTCRETE shotcrete experiences lower expansion stresses than normative ones [2] and does not cause longitudinal and transverse cracks. In the same time, metal pipe experiences double deformations of expansion and stress that are significantly higher than PLASTCRETE has. The same deformation sign in both parts of the system shall be considered as a guarantee of the absence of outward stresses between metal pipe and PLASTCRETE.

5. CORROSION RESISTANCE

As shown in the report of “DETERMINATION OF RESIDUAL SEVICE LIFE OF DISCHARGE PIPELINE OF AMU-ZANG 2 PUMP STATION” about metal pipeline condition, electromechanical corrosion and abrasive water flow explain the reduction of pipe wall thickness for 0.15 mm, annually. Electrostatic field, generated by water flow in pipe, induces ion-cation exchange with metal, i.e. its oxidation with weakening of atomic lattice.

Every second, emerging metal oxide “film” is removed by abrasive particles flow of ground, sand and organic elements, which are brought by water flow.

It should be noted, where under possible silt on the bottom and turning (bends) pipe sectors shall not have metal corrosion tracks. Silts in the form of thick layers reach petrifaction density and are hardly removable from pipe surface. Naturally created dielectric of this layer also has density that is enough to resist abrasive water flow with sand.

During protection and restoration works of the concrete aqueduct in Mojave Desert (www.shieldcrete.com), it was pointed out that the plastered walls and ceilings more than 100 years ago are not only undamaged but also acquired glassiness. This can be explained by developing of calcium depositions on the surfaces of plaster, in which cement and lime have been crystallized during a long time period in water, containing ground minerals.

The aqueduct is 200 miles in length with height differences up to 100 meters, experiences nonrecurring water pressures of up to 50 bars at seasonal start.

The city water channel of Los Angeles have been repairing metal and concrete aqueducts using PLASTCRETE material with additive KALMATRON® KF-A, which has passed initial tests and annual examinations as well. The works on aqueducts are being continued. Reference letter from Department of Water and Energy under Mayor’s office of the City of Los Angeles, USA is attached [4].

6. CONCLUSION

6.1. Calculated stress assessment results of PLASTCRETE shotcrete shows its independence from its elastic properties, and also on geometric and strength residual properties of metal pipes.
6.2. Calculation results of temperature stresses and deformations under average stable and extreme temperature conditions during winter and summer periods prove that a pipe made from PLASTCRETE shotcrete with the thickness of 20 mm will not be subject to damages and cracks.
6.3. Under extreme temperature conditions during winter and summer periods, the value of temperature stresses and deformations of PLASTCRETE shotcrete – 20 mm does not exceed the normative values [2].
6.4. During PLASTCRETE preparation in accordance with mix design [2] and application on the internal surface of pipeline in compliance with water to cement ratio, the operating service life of PLASTCRETE shotcrete layer with the thickness of 20 mm without damages and cracks shall equal to 30 years under satisfactory operation of roller supports.
6.5. The durability of PLASTCRETE on water abrasion, as a carrier of abrasive particles delivered from the river through standard filter screens, shall be 100 years.
6.6. The strengthening of PLASTCRETE end sectors in places of pipe geometry drops shall ensure not only abutment strengthening, but also the spacing resistance of PLASTCRETE from hydraulic reactive stresses along the length.
6.7. Destruction to resistance, corrosion stability, waterproofing and absence of shrinkage deformations and cracks are provided in appendix "KALMATRON® KF-A for concrete of high grade" [3].
6.8. The presence of transverse pipeline deformations during water hammer shall be absorbed by angled elements of expansion bends. Damping transverse reactions by pipe section prove non-operating condition of roller supports that may result in unpredictable emergency condition along pipe section. Therefore, the rehabilitation of roller supports shall be carried out as the first priority, and must be maintained in a good condition by Pump Station operators throughout pipeline operational period.
6.9. The repair of roller supports is a necessary condition for pipeline operation, and also guarantees compliance of operation conditions of PLASTCRETE layer along the entire length of pipelines.
6.10. Control welding of joints, external isolation works, fastening the bolts of transverse ribs, and also strengthening the ribs and installation of additional pipe section strengthening are not required.
6.11. The required resistance of shotcrete to abrasion by abrasive water flow, significant hydraulic pressure drops and thermal stress in the sections of metal pipe and PLASTCRETE, as thermomechanical pair, are ensured by high strength of cement stone as of 2232 kg/m^3, stated in the provided mix design of PLASTCRETE [2].
6.12. The water to cement ratio shall be from 0.38 to 0.43 [2].
6.13. PLASTCRETE application can only be performed at outside air temperature of **-** 15°C or above.
6.14. After the application of PLASTCRETE, the pipeline shall be put into operation after 7 days.
6.15. In order to guarantee design service life of the pipeline, and taking in to account vibration and large number of welding seams and cracks on existing pipeline core, shotcrete layer must be applied throughout the whole pipeline.

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Chemical reaction between metal and KALMATRON® KF-A:

Film oxide on the pipe surface represented by the iron, iron-ferric oxides, which are not able to oxide further, but easy dissolves by acidic electrolytes of KF-A partly or completely. Therefore, on the moment of contact PLASTCRETE with metal its etched rust become as an ionic field, which naturally attracted by the metal pipe's cations. All process takes a few minutes.

Farther layer hardening implements structure forming process settled on the metal surface as a center of crystallization. This process may take up to 4 hours or less. Practically, this is an ideal bond between two materials where boundary zone between pipe and PLASTCRETE is a diffusion inert crystal – like body.

"ag" is settled cement aggregate after coagulation".

Exchange ⇔Dissolution⇔Fusion > Frame Forming stage of KALMATRON reactivity with oxides:

$2NaNO_3 + Ca(OH)_2 \Leftrightarrow Ca(NO_3)_2 + 2NaOH;$ (1)

$Ca\ (NO_3)_2 + Ca(OH)_2 \Leftrightarrow 2CaOHNO_3;$ (2)

$CaCl_2 + Ca(OH)_2 \Leftrightarrow 2CaOHCl;$ (3)

$CaOHNO_3 + ag^- \rightarrow CaOHNO_3 \cdot ag\downarrow;$ (4)

$CaOHCL + ag^- \rightarrow CaOHCl \cdot ag\downarrow;$ (5)

$3Ca(OH)_2 + 3Na_2SO4 + 31H_2O + Ca_3(FeO_3)_2 \rightarrow$

$\rightarrow 3(CaO \cdot Fe_2O_3 \cdot CaSO_4) \cdot 31H_2O\downarrow + 6NaOH;$ (6)

$Ca(OH)_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2\ NaOH;$ (7)

$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2\ H_2\downarrow;$ (8)

$3Ca(OH)_2 + 6NaCl + [3CaO \cdot Fe_2O_3] + 30H_2O \rightarrow$

$\rightarrow 3\ [CaO \cdot Fe_2O_3 \cdot CaCl_2] \cdot 30H_2O\downarrow + 6NaOH;$ (9)

$3Ca(OH)_2 + 6NaNO_3 + [3CaO \cdot Fe_2O_3] + 32H_2O \rightarrow$

$\rightarrow 3[CaO \cdot Fe_2O_3 \cdot CaNO_3] \cdot 32H_2O\downarrow + 6NaOH$ (10)

SHOTCRETING INSIDE PIPELINE

SHOTCRETE UNIT INSIDE PIPELINE

SHOTCRETE LAYER SURFACE INSIDE PIPELINE

SHOTCRETE LAYER SURFACE INSIDE PIPELINE

LIST OF USED SOURCES

[1] – "DETERMINATION OF RESIDUAL SEVICE LIFE OF DISCHARGE PIPELINE OF AMU-ZANG 2 PUMP STATION" and "WATER HAMMER ANALYSIS".

[2] – "PUMPABLE MIXES FOR PLASTCRETE JOBS", KALMATRON CORPORATION.

[3] – "KALMATRON K-FA FOR HIGH PERFORMANCE CONCRETE", KALMATRON CORPORATION.

[4] - "REFERENCE LETTER FROM DEPARTMENT OF WATER AND ENERGY UNDER MAYOR'S OFFICE OF THE CITY OF LOS ANGELES, USA".

GENERAL DATA

1. Products of KALMATRON® & K100® are non-hazardous, non-flammable, non-explosive;
2. Trade mark KALMATRON® patent #2,724,832;
3. Trade mark K100® # 006915839; #3,680,881;
4. NSF Reg.# 136880; Category Code: R2, RX-2;
5. DUNS #859984069;
6. Harmonized Brussels' Code # 3824.40.0000;
7. Packaged into plastic bags or 5 GL plastic buckets or 1000 Liters IBC;
8. ASTM C779 "Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces".