Issues of ensuring the design durability of reinforced concrete supports of the main pipelines of oil refineries

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Abstract. The aggressive environment of oil refineries contributes to increased corrosion of reinforced concrete supports of trunk pipelines. This is primarily due to the increased concentration of acid gases. The article presents results of the analysis of the gas-air environment of an oil refinery and its impact on primary support measures. It was established that when using typical reinforced concrete supports made from B15 W2 concrete, the protective layer with a thickness of 15 mm becomes neutralized 3-6 years after the operation. To ensure continuous 25-year operation, it is necessary to increase thickness of the protective layer to 35 mm. To increase the durability of the structure, it is proposed to replace steel reinforcement with "metal-fiberglass" or hybrid fiberglass one.

1. Introduction

Pipeline transport is one of the most popular in the oil, refining and petrochemical sectors of the national economy. Its main advantages are efficiency and quick transportation of liquids and gases. However, there are a number of disadvantages: low life cycle of pipelines and building structures; danger of damage to the environment due to technological straits; great variability of construction methods, depending on the construction area. These shortcomings cause pipeline failures contributing to the premature decommissioning of building structures and formation of foci of technological disasters. The most common causes of failures [1] are the use of low-quality building materials and products, errors in the design of structural solutions, violation of building codes, performance of poor quality construction and installation works, etc.

One of the common methods for building pipelines in industrial zones is overhead construction on special overpasses. In the oil refining plants, overpasses with reinforced concrete columns are most widely used. This is due to their increased fire resistance compared to the metal ones. A typical solution for reinforced concrete supports of overpasses involves the use of concrete with a compressive strength class B15 or B20, with a waterproofing grade of W2 and W4. The thickness of the protective layer is 15 - 20 mm.

The life cycle of these supports is small. In [2], it is indicated that when examining the supports of the pipeline, which is an element of the technological scheme for processing natural gas, 15 years after the operation, vertical and transverse cracks, and violations of the continuity of the concrete protective layer (flakes and chips) were revealed. The total number of columns with defects was 64%.

It is characteristic of reinforced concrete used in pipeline transport facilities that in most accidents it has insufficient primary protection measures (thickness of the protective layer, cement consumption,
etc.) and lacks secondary protection measures. Another cause of accidents is a change in the operating environment, for example, in the transition from a dry mode to a wet one.

The main ways to increase the durability of reinforced concrete include: the use of dense concrete and plaster compositions (waterproof grade W8 and more); rational thickness of the protective layer; additional coating of steel reinforcement with special protective compounds, etc.

It is necessary to assess the resistance of reinforced concrete in an aggressive environment of the oil refining complex, increase its durability and develop effective protection measures. Therefore, the aim of this study is to determine the influence of an aggressive environment on the reinforced concrete supports of overpasses located on the territory of an oil refinery.

2. Analysis of the aggressive environment of the refinery

The formation of defects and damages in the pipeline supports is associated with unfavorable temperatures and humidity, as well as aggressiveness of the environment.

Many technological processes occur at high pressures and temperatures of up to 500 °C [3]. Technological devices are located in open areas; therefore, these processes affect the temperature-humidity mode of operation. For example, during the winter period, the air temperature in the apparatus zone can range from +2 °C to +35 °C at a temperature of five days in the region equal to -35 °C. Relative humidity varies from 20 to 90%. In summer, the temperature reaches +40 ... +50 °C.

In processing hydrocarbon feedstocks and its products, acidic gases such as hydrogen sulfide, sulfur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, carbon dioxide and others are released into the atmosphere. The main reasons are as follows: technological needs (any complex has special burners for continuous or periodic gas combustion); uncontrolled emission due to tightness damage (the main cause of metal corrosion); emergency reset, etc. In [4], it is indicated that the main technological installations that contribute to the emission of acid gases are: combustion plants emitting sulfur dioxide, nitrogen oxides and solid particles, and others. When burning gases, combustion products in the atmosphere are distributed from the flare unit at a distance of 3 ... 4 km [5].

Concentration measurements in the areas of installation of overpass columns using the “HT2000” digital gas analyzer showed that the concentration of carbon dioxide is about 0.10 ... 0.15% in the winter period. Measurements were taken on the outside of the Ufa refinery in 2018. The concentration of CO₂ in a radius of 50-100 m from the flare unit reaches 0.40% when winter is poor. Measurements were taken on the outside of the Salavatnefteorgsintez plant.

An analysis of the operating environment by the degree of impact on reinforced concrete of the overpass columns, taking into account the indexation provided by GOST 31384-2008 “Protection of concrete and reinforced concrete structures from corrosion”, showed (Figure 1) that the existing exposure conditions have the following indices: XC4 - corrosion of reinforced concrete as a result carbonation of concrete in zones of alternate wetting and drying under moderate aggressive effects of gas; XD2 and XD3 - reinforced concrete is exposed to chlorides, including salts and industrial waters containing chlorides (overpass supports are often performed through roads both for the plant use and streets). In addition, reinforced concrete of the aboveground part of the overpass support is affected by alternate freezing and thawing without combiners for vertical XF1 and horizontal XF3 faces, the effect of erosion due to the presence of large aerosol particles in the air of the production zone, and the effect of acid rain, which contribute to the corrosion of concrete in liquid environments. In special cases, there is a moderate impact of an aggressive environment on the foundations due to technological strains XA2.
Figure 1. Indexing of aggressive media on reinforced concrete overpasses of a process pipeline: a - schematic diagram of the impact of an aggressive environment; b - general view of the reinforced concrete support with exposed reinforcement: 1 - reinforced concrete support; 2 - supporting structure of the pipe “lezhka-opora”; 3 - trunk pipeline; 4 - column foundation under the support

The impact of CO$_2$ on the protective layer of the reinforced concrete structure carbonizing concrete lowers the pH of the pore fluid from 11.8 to 9 in the area where the steel reinforcement is located. If aggressive sources (chlorides, water, oxygen) get in the environment, the steel corrodes and cracks the protective layer. Corrosion processes in reinforced concrete are more intensive with an increased concentration of CO$_2$, temperature and humidity of 50-60%.

3. Determination of the rational thickness of the protective layer by the criterion of CO$_2$ exposure

Currently, the use of concretes of low and especially low permeability is a common method in monolithic construction. When using these types, the class of concrete becomes B25 or higher. This is due to a lower water-cement ratio, the use of formulations including special additives, fillers. It should be noted that the cost of structures made of these concrete is increasing, which affects technical and economic indicators of the construction of an elevated trunk pipeline. A more rational option is to use these types of concrete to repair the existing supports.

A more optimal option is to determine the rational thickness of the protective layer of concrete. Under the action of CO$_2$, the purpose of thickness of the protective layer will depend on the kinetics of concrete carbonization. Currently, there is no single approach to the analytical calculation of this indicator. Many researchers describe this process by Fick's First Law in the form of a differential mass transfer equation. An analytical model describing the kinetics of concrete carbonization is as follows [6]:

$$x = \sqrt{\frac{2 \cdot D_{eff} \cdot C}{m_0} \cdot t},$$

$$m_0 = 0.4 \cdot Cem \cdot p \cdot f,$$

where $D_{eff}$ – effective coefficient of diffusion of CO$_2$ in concrete, cm$^2$ / s; $C$ – CO$_2$ concentration in relative units; $m_0$ – cement stone reaction capacity; $t$ – impact time, c; $Cem$ – cement consumption, kg / m$^3$; $p$ - the amount of basic oxides in cement in terms of CaO in relative quantities by weight; $f$ –
the degree of neutralization of concrete, equal to the ratio of the number of basic oxides that have interacted with carbon dioxide, to their total amount in cement.

Based on the results of accelerated testing methods for fine-grained concrete of different densities at a CO\textsubscript{2} concentration of 5% and 75% humidity, a mathematical model taking into account the transition to the actual gas concentration was proposed in [7].

\begin{equation}
    x = \left(0.9 \cdot \frac{W}{W_{\text{cem}}} - 0.34\right) \sqrt[n]{t} \cdot \frac{C}{C_0},
\end{equation}

where \(W_{\text{cem}}\) – water cement ratio; \(C\) – actual concentration of CO\textsubscript{2}, %; \(C_0\) – reference concentration of CO\textsubscript{2} equal to 0.03 % \(n\) – the root index, depending on the sample density varying within 1.9…2.45; \(t\) – impact time, year.

To analyze the kinetics of carbonation of concrete of the overpass supports according to models (1) and (2), the following dependences were obtained (Figure 2).

\[x = \left(0.9 \cdot \frac{W}{W_{\text{cem}}} - 0.34\right) \sqrt[n]{t} \cdot \frac{C}{C_0},\]

**Figure 2.** Dependence of the carbonation depth of concrete W2 on the flyover operation period

The following parameters were taken as initial data. The design service life is 25 years (7.9 \times 10^8 s), adopted for structures operating in aggressive environments of oil refineries in accordance with GOST 27751-2014 “Reliability of building structures and foundations. Key Points.” The water-cement ratio of 0.65 is characteristic for B15 concrete [8]. The effective coefficient of diffusion of CO\textsubscript{2} in concrete for a water-cement ratio of 0.65 is 2.4 \times 10^{-4} \text{cm}^2/\text{s} was adopted on the basis of experimental data obtained using the method of electrical conductivity of concrete. For the manufacture of reinforced concrete supports, cement “CEM II / V-Sh 32.5N” with a flow rate of 250 kg / m\textsuperscript{3} is used in the amount of CaO 64.61%. The average value of the degree of neutralization of concrete is 0.6. The average concentration of CO\textsubscript{2} in the refinery zone is 0.1%. The root index, which depends on the density of the sample for a water-cement ratio of 0.65 is 1.98.

Figure 2 shows two forecasts of concrete carbonization - optimistic and pessimistic. Both forecasts showed that the design thickness of the protective layer of 15 mm will be achieved 3 ... 6 years after the operation. These data are subject to the results of an inspection of the support structures 5 years after the repair [2]. Analyzing the data obtained, we can conclude that the most rational thickness of the protective layer of concrete should be at least 35 mm with concrete density of W2.

4. **Improving the durability of reinforced concrete supports due to the use of metal-fiberglass reinforcement**

An innovative way to increase the durability of reinforced concrete structures is to replace steel reinforcement with corrosion-resistant polymer materials with a high tensile strength. One of the most
promising materials is non-metallic fiberglass reinforcement. Their significant disadvantages are: low modulus of elasticity; brittle fracture, inability to use a welded frame - usually connected by knitting (using steel wire, plastic clamps) or bonding with a polymer composition such as epoxy adhesive, etc.

To improve the mechanical properties, it was proposed to add a steel core [9–11] (Figure 3). This armature is called "metal-fiberglass" or "hybrid" fiberglass.

![Figure 3. Metal-fiberglass (hybrid) rod: a - the process of installing a steel core in a sample; b - is a diagram of a metal-fiberglass rod; 1 - steel core; 2 - a bundle of fiberglass threads; 3 - multiple winding](image)

According to [9], fiberglass reinforcement with a diameter of 10 mm was used as the main rod, the steel core was made of fittings of a smooth profile “BP-I” with a diameter of 3 mm. These samples were obtained by excavating the middle part of fiberglass reinforcement with a diameter of 3.5 mm. Epoxy adhesive was initiated into the hole and the steel rod was inserted. After hardening, the samples were subjected to tensile and thermal stress tests. According to the results of tensile tests, an increase in the modulus of elasticity of metal-fiberglass reinforcement was obtained. The stress-strain state of rods was established in [10], they exhibit bilinear behavior, i.e., there is a certain amount of plasticity compared to the brittle fracture of a conventional fiberglass rod, the elastic modulus reaches 145 MPa, depending on the ratio of the outer and core diameters. The studies described in [11] showed that for a hybrid carbon fiber core with a total diameter of 12 mm and a core diameter of 8 mm, the elastic modulus was 224 GPa. The production of such rods should be carried out according to the traditional technology by assembling a bundle of filaments and a core followed by their subsequent treatment with epoxy compound. Focusing on the above data, we can assume that this type of reinforcement can reduce material consumption and increase the corrosion resistance of the structure.

5. Conclusion
Studies have shown that when using class B15 concrete with a waterproofing grade W2, the thickness of the protective layer of reinforced concrete supports of 15 mm will be neutralized 3 ... 6 years after the operation in the oil refinery. To ensure a design life of 25 years, the rational thickness is 35 mm. Otherwise, it is necessary to reduce the permeability of concrete, or use secondary protection measures. One of the effective ways is to replace steel reinforcement with "metal-fiberglass" or hybrid one.

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