COOLERS OF THE EMERGENCY COOLING SYSTEM FOR VVER1000 TEMELÍN

J. PRCHAL, Královopolská RIA, a.s., Brno, Czech Republic

Královopolská, a.s. has been a producer of plants for oil processing, chemistry, power engineering etc. for more than 100 years. The whole period of its existence is characterized by the permanent efforts to comply with the demands of customers, to anticipate the technology development and to supply plants which are reliable and of a considerable service life.

In connection with this basic philosophy experience has been gathered by long lasting operation in customers' plants and investments have continually been made in our own technical development to minimize customers' problems and faults. The given example of the TQ exchangers is, as we believe, a good illustration of this attitude.

The specialization and tradition of Královopolská, a.s. are the reasons why, from the very beginning, it has taken an active part by its deliveries in the Czechoslovak nuclear power programme. Long-standing experience with the production of plants from austenitic steels has made it the largest and, in the end, the final supplier of the so called secondary circuit plants. In connection with a gradual transition from individual piece deliveries to the final supplying of whole operational sets both the form and contents of the technical processing have changed from simple documentation to project comprehensive supplier activity. In this way, Královopolská, a.s. has become a permanent participant in the construction of all the Czechoslovak nuclear blocks starting with the A-1 power plant.

The total volume of the deliveries made in all production fields reaches tens of billions, so that this company has become a member of the exclusive club of the largest suppliers of the power complex of the Czech Republic.

The volume of deliveries for nuclear power stations has included emergency and auxiliary systems, piping, fittings and pumps, barbotage plants, exchangers, filters and other technological devices, basins for treatment and temporary storage of fuel elements, tanks and reservoirs of various sizes, special plants for waste and RA water treatment, treatment of RA waste and its dumping by bitumenation and cementing etc.

In connection with such a large scope of the delivery programme a number of problems of not only technical character have been encountered, which always occur when a technically sophisticated complex is implemented.

An important problem in our sense is the conflict of the basic project decision - the selection of the principal material for the production of plant (austenitic chromium-nickel steel of the 08Ch18N10T type) in its contact with the environment, represented in the given case by complex problems of the composition of technical cooling waters. Even though at first the problems of the selection of this material seemed to be definitely solved and without conflict, the operational experience showed that this attitude was wrong.

The overall unfavourable situation in the area of „clearness" of waters in Czecholsovakia was forced by the conflict of industrial landscape with a high degree of chemistry polluted agriculture and transport against the geographic background of a European water-shed with the presence of upper streams of rivers with small flow, which leads to a high degree of pollution generally, particularly then to high pollution by chlorides and other aggressive admixtures which make it necessary to pre-purify the river water before using it. However not even this degree of purification was sufficient and it could even cause other accompanying problems (creation of reagent sediments in the cases of technology faults, intrusion of micro-organisms etc.), which all supports and increases the negative influence of chlorides.

The great distance of the general developer who was not used to problems of this kind and, on the contrary, the perfect ignorance of the local experience and conditions and the institutional fragmentation of the decision making process along with the buck-passing of the totalitarian regime led to very strange anomalies in decision making. It is really strange that, in the end, it was still possible to solve the given problem under the totalitarian regime. If this had not happened we could surely have expected significantly more serious problems in the operation of Temelín Power Station than those that really did happen at Bohunice Power Station and Dukovany Power Station. We can say with justification that, by the efforts of Královopolská, one of the big problems of the future operation of Temelín Power Station was solved in advance with a preventive force, since the comprehensive assessment of the situation leads to the conclusion that to produce „ideal" cooling water is virtually impossible despite considerable costs and technical skills. We do not even have to take into consideration the influence of unfavourable environmental prognosis.

As a consequence of the above described situation, very often the plants from the classical austenitic steel of the 08Ch18N10T type have been attacked by corrosion caused by cooling water.

In 1968 Královopolská supplied 6 pieces of large vertical D_2O coolers with the tube bundle made of U-tubes out of the Ch18N10 type steel with low carbon content to the A1 nuclear power plant. Heavy water in tubes, cooling water in the inter-tube space. Maximum temperature of D_2O 90°C, tube wall temperature approx. 60°C because of the cooling water. In 1974, after a relatively short operation period, one tube bundle was badly damaged by pitting and by corrosion cracking in areas outside tube bends. Maximum chloride content was 105 mg per liter; the project envisaged 20 to 25 mg per liter. The water was taken from the river Váh, the increased chloride contents was apparently caused by the salting of roads in Winter and the influence of this had been rather underestimated in the project. The tube bundle of the damaged apparatus was not entirely submerged in the cooling water as a consequence of wrong de-areation. The leakage of the bundle was detected only after a considerable volume of heavy water had escaped whose radiation was detected as far as in Budapest. The apparatus was put out of operation using a bypass. The repair was not performed since, shortly after this accident, A1 was put out of operation.

After this negative experience, Královopolská decided to use austenitic steel with three per cent of molybdenum and INCOLLOY-600 for the production of the SAOZ exchangers for JE V1 Bohunice. These apparatuses have been in operation for 18 1/2 years without any corrosion problems reported to the producer.

At V2 Bohunice from 1981 to 1982 24 out of 29 pieces of large tanks of the 08Ch18N10T type steel supplied by Královopolská were attacked by corrosion on a mass scale. The tanks were attacked not during operation but during a water infusion test. As it was not possible to get the required volume of demineralized water for the test, it was allowed to use drinking water. An error occurred when the intake piping was connected in an excavation and, consequently, the tank was filled with water with a chloride content of 110 to 370 mg per liter. The pitting was progressing at a high rate and into a considerable depth (through-pits in bottoms and walls of the tank of a thickness of 5 to 6 mm) About 3,000 damaged spots were found. The repair was complicated and costly. Parts of bottoms were replaced. There was a heavy suspicion of the corrosion being accelerated by microbes.

At the 1st and 2nd blocks of V2 Bohunice in 1896 corrosion attacks of all 6 SAOZ exchangers were detected during operation. The apparatuses from the 08Ch18N10T type material supplied by Královopolská were attacked on a considerable scale by slotting corrosion in the place of the floating head packing and also by pitting corrosion on surfaces wetted by technical cooling

water. The operation time until the detection of the corrosion had been 3 years (1st block) and 1 1/2 years (2nd block).
At all four blocks of V3 Dukovany the same exchangers supplied by Královopolská were attacked i.e. all 12 pieces. The damage caused by the corrosion was more intensive. Apart from the slotting corrosion of the packing point the pitting corrosion was considerably stronger. Numerous leakage points were detected on the apparatuses particularly in tubes. In May 88 two of these exchangers of the 1st block were replaced by new ones made of steel containing 3 percent of Molybdenum.
All the above mentioned cases were caused by technical cooling water. The total damage incurred by them amounts to more than 300 million CZK at the present prices.
The above considerations stress the extraordinary importance of managing the operational reliability which is of a size overriding the original investment demands.
When making a decision on the further course of action it was not possible to take into consideration only the technical analysis, although this aspect was the most significant one. There were complications on the upper storeys of the system - at the level of the valid Soviet nuclear standards as well as in the sphere of administration, management and contracts:
The Czechoslovak administrative bodies, mainly the Ministry of Heavy Industry and the Ministry of Fuels and Energy took a firm stand against the change of material and exerted brute force to make the producer place an order for the TQ exchangers with a Polish specialized producer (according to the relevant international specialization agreements), who produced a Soviet design from the classic austenitic material. There was the question of not endangering the planned times of delivery behind this attitude. This and other unbelievable aspects, which, fortunately, today are ridiculous, were at that time very serious and almost insurmountable.

It took more than 3 years before the matter was settled. Since the solution of the given problem concerned

- nuclear safety
- partially the Soviet zone of projecting,
- the agreement on mutual deliveries and specialization of production of plants in the member states of the Council for Mutual Economic Assistance associated in MChO Interatomenergo,
- mutual agreement on the changes in the project,

it was necessary to meet several times at Interatomenergo and its Soviet organizations to deal with the problem. As the problem also concerned immediately the interests of Poland, it was dealt with many times during a series of commercial and technical negotiations between Czechoslovakia and Poland.

It was only at the beginning of 1989 that the matter took a turn for the better and there was a positive development. Backed by a previous effective support of the building contractor of the Nuclear Power Plant Temelín, the Czechoslovak Commission for Atomic Energy and others we stopped the unfruitful tactics of persuading and took active steps to ensure the attestation of a new material and new design of the TQ exchangers.
This had successfully ended the period of most disgusting tug-of-war. The transition to a new material and design of the TQ exchangers (plus four other exchangers for the Nuclear Power Plant Temelin) was successfully finished. The production of six TQ exchangers was finished by August 1993 without any problems.

It follows from the above mentioned facts that we have come across a large number of cases of serious corrosion damage on various exchangers from classic austenitic steel stated in the project cooled by treated water.
This damage caused large economic and material losses. Královopolská flatly refused to go on in this series of faults even despite the pressure exerted by the superior Ministries and it took on the appropriate responsibility to successfully solve this complicated problem.
Therefore it was decided that all the parts of the emergency cooling exchangers for Nuclear Power Plant Temelín that will get into contact with the cooling water will be fitted with two-phase steel despite the fact that this steel requires a more sophisticated technology.
On the other hand the two-phase steel is characterized by significantly better mechanic properties than the austenitic steel and it also has a lower temperature extensibility coefficient and thus higher thermal conductivity, which significantly reduces the thermal stress.
For this reason, Královopolská, after adopting the decision on the change of material, also decided on a fundamental change and modernization of design. The AO 257 572 heat exchanger with helix partitions was taken as a basis with extensive research and hundreds of operating measurements performed with hundreds of produced exchangers. The advantage of this patented solution is a significant intensification of the heat exchange at a minimum loss in pressure, which leads to the possibility to use tubes of less diameters and to an overall increase in compactness. This has an important effect in the total wetted and thus by the possible corrosion attacked area.
Another important design principle used in the TQ exchangers is the utmost simplicity which is the source of the overall and other reliability and which is the result of long-standing experience and tradition. The most important consequence of this simplicity is a reduction of the number and length of the welded joints and other risky design points.

Further quality ensuring in the TQ exchangers was performed through the following measures:
- attestation procedure, which approved the use of two-phase steel and the new design of the exchangers;
- attestation procedure, which proved the applicability and quality of the welding technology and the welded joints themselves;
- technological development of mechanical and forming operations with a subsequent check to exclude the degrading of the corrosion resistance by their influence;
- performing extensive checking strength calculations with a feedback for the design;
- the control measures in production, next respecting detailed rules for work with non-rusting anticorrosive steels, tests by twice demineralized water, special leakage tests by helium etc.

To a considerable degree in parallel with this process, the design development was running, process - technological calculations and the design process itself. This parallelism was dictated by the loss of several years spent in a rather non-productive way for the negotiations with a number of organizations and institutions as well as by the rapid construction of the building part of the Power Station Temelín (the incorporation of the TQ exchangers in the construction was only possible in a certain period of the construction). Moreover this parallelism helped the licensing procedure since it was possible to assess a rather progressed solution.
A special development team recommended already at the beginning of the preparation of changes that the new design conception should be based on the long-standing experience of Královopolská as a producer of heat exchangers, its references as well as the results of following the world trends to modernize. This tendency led to a direct application of their own

- tested patented solution [2] - according to AP 257572 (flow organization in the inter-tube space using „helical" oblique partitions). Next it was decided to keep the floating head and the two-way tube bundle (the original Russian solution) even though it was basically possible to employ also another conception.

The experience with implementing the AO at the time of the decision was quite considerable; the relevant research, measuring on models, pilot-exchangers as well as instrumented measuring on a number of exchangers of the new refinery Kralupy definitely proved the advantages of this solution - the possibility of heat transfer intensification and optimization size and economic factors optimization and minimization of losses in pressure (energy). Before the decision to apply the AO to the TQ exchangers was adopted, Královopolská produced 650 pieces of these various exchangers which proved the required functionality of the declared advantage as well as the absence of faults to be claimed.

The idea of the AO contribution is the removal of the insufficiencies of the classic arrangement of partitions used up to then.

Generally the partitions are used to organize the flow of the working substance in the inter-tube space and, at the same time, to create a support for the tubes whose pitch influences also the frequency of their own oscillations, which can, in a short time, damage the bundle or destroy it completely.

The hitherto designs of tube apparatuses most frequently transversal plane partitions are employed either of the segment or disk type. The segments are formed by cutting off a circular surface on one or two sides and they are placed on the tube bundle in an offset arrangement. The disk partitions have the form of a circular or annular surface where both surfaces alternate on the tube bundle.

A common advantage of the disk and segment partitions is the possibility to „set" the flow area of the channel by changing the sizes of their pitches and sections and thus attain higher velocities of the medium flowing through the inter-tube space and higher coefficients of the heat transfer. A drawback, on the other hand, is that these measures cause a considerable increase in pressure losses. Moreover in the wakes before and after the partitions there are dead corners which put part of the heat exchange area out of action and have, apart from this, a negative influence on the intensity of fouling in these areas. The higher losses in pressure then, for the whole service time of the exchanger, increase the costs of the transport of the working substance, which easily surpass the price of the exchanger.

The deficiencies of the described types of partitions are, while keeping all their positive properties, removed in partitions for tube bundles of tube apparatuses made by the author's certificate [2] which are characterized by being formed by segments creating at least one interrupted or contiguous helix surface in the inter-tube space.

The helix surface of the partitions not only enables perfect washing of the tube apparatus, which contributes to a reduction of the creation of dead corners and of the tendency to fouling but it also enables uninterrupted transport of the medium through the inter-tube space of the apparatus without any significant losses in pressure for there are no abrupt changes of the flow direction and contraction, which are present in the majority of the partition types used hitherto.

The idea of the improved arrangement of the helix partitions for the tube bundles of tube apparatuses which are formed by segments forming an interrupted or contiguous helix surface in the inter-tube space of the apparatus is that the helix lead angle lies between 35° and 40°.

It was also discovered by experiment that the optimum value of the angle is 40°. At this helix lead angle the heat transfer convective coefficient value corresponds to the values at the transversal inlet and the losses in pressure are the lowest. From this it follows that, in the technical practice, mainly helix partitions with the helix lead angle equal to 40° or a value near to it.

Another important fact is also that a contiguous rotationally progressing (which means a helical one) flow with extremely small losses in pressure is formed in the inter-tube space and thus the influence of short-cut currents through leaks between the partition and the exchanger jacket is suppressed. The whole tube bundle of the tube plate are made of two-phase non-rusting steel of the type 02Cr22N5AM3 (17381).