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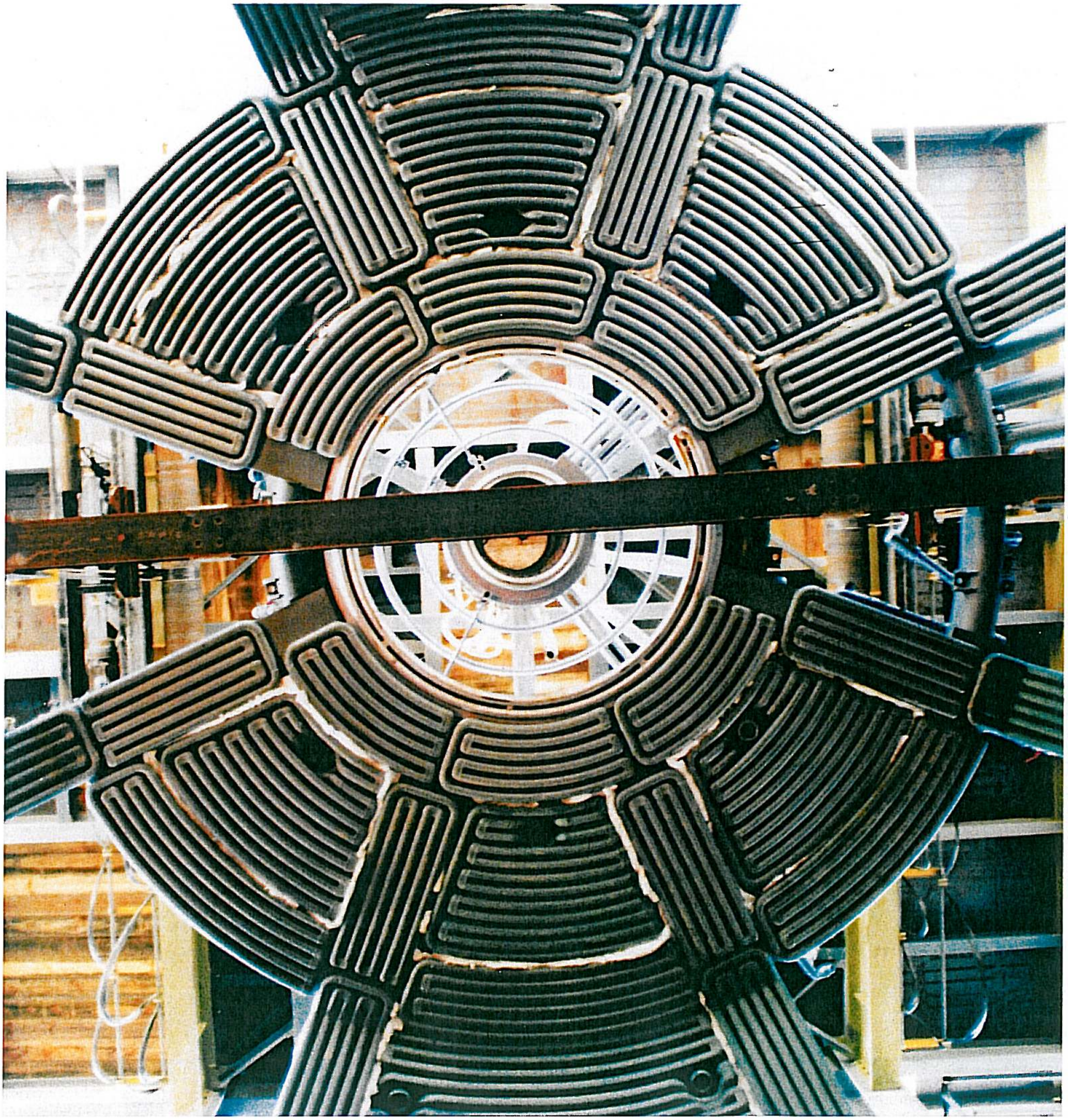

Water-cooled vessels in modern high-performance electric arc furnaces

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This article summarizes some experience in the construction of water-cooled plant parts for the modern electric arc furnace. Causes of failure and solution possibilities described are often recurring factors. Due to the multitude of influencing factors with regard to the lifetime of components, it is of prime importance to examine the causes of failure of each individual case. The constructional layout of the cooling areas is to be optimized with due regard to some general construction recommendations as well as the specific factors of influence, production procedure and materials used for the particular furnace.

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Constructional principles. Electric steel production has gained very much in significance in the last three decades. This trend has continued in recent years. Without making a differentiation between AC and DC furnaces it can be noted that the layout of new and modified electric melt aggregates is unequivocally leading towards powerful, large dimensioned furnaces with constantly increasing tapping weights. Short tap-to-tap times are reached through continuously growing input on both the electrical as well as the chemical-metallurgical side.

Processing costs in electric steel production are heavily influenced by energy costs because steelmaking is very energy-intensive.

Furthermore, the high output of liquid steel requires high plant availability. Today minimization of disturbance and maintenance times is more important than ever. Consequently, at the beginning of the 1980's the replacement of refractory material by large-surface water-cooled wall and roof panels became prevalent.

The additional energy consumption of electric arc furnaces with cooled panel and roof lining, in the literature stated to be between 10 and 20 kWh/t, is compensated by a multitude of advantages in the field of plant availability and maintenance. This trend of development will be accelerated by the increasing vessel size because in comparison with smaller plants, larger furnace units have a smaller liquid surface/liquid quantity proportion and, hence, heat radiation loss is less.

Layout. The modern electric arc furnace vessel essentially consists of a lower vessel with complete refractory brick lining and the tapping area. The upper vessel is mounted to it by means of a quickly detachable flange connection. The fitted furnace roof is attached on the side of the portal and is brought into its working position during the melting process only by means of a fixing device.

Both the fitted upper shell and the furnace roof are completely designed as water-cooled components. The design principle of both components is similar. A cantilever supporting structure (cage) in the form of a pipe construction provides for the calculated static stability as well as for the necessary cooling water distribution in the system. Individual cooling elements with different geometrical shapes are fastened to the supporting structure. Simple and quickly detachable connections provide for short replacement times, **figure 1.**

Supporting framework. The complete cage construction consists of pipes continuously supplied with water. Therewith it is guaranteed that the dimensions of the necessary supporting components can be kept small (the supporting structure is permanently cooled). Furthermore, the supporting framework is resistant to direct radiation influences, which extremely extends its service life. All supply connections for the cooling panels are integrated inside the supporting framework, **figure 2.**

Cooling panels. Cooling panels are the most important parts of a water-cooled system. They are subjected to a multitude of stresses during their service. A detailed examination of the different kinds of wear will give an answer to how their life can be extended. Essential factors of influence and solution variants increasing the lifetime are presented below.

The strongest *mechanical load* on the panels occurs during the charging process. Contacts with heavy scrap parts lead to deformations of the cooling pipe or cooling coil. Individual tube coils will be that strongly deformed that they have to be replaced. If the walls of the cooling pipes are too thin, the impact during charging leads to deformation of the tube or even splits, i.e. leakages occur.

The determined *minimum wall thickness* is about 8 mm. In this dimension range pipes are sufficiently resistant to mechanical load and, on the other hand, with this thickness an adequate cooling of the tube wall is guaranteed. Further information on this aspect will follow below in the section on "thermal stress". Mechanical resistance is also strongly influenced by the constructional layout of the cooling coils. In the case of vertically running pipes there is the additional problem of having to pull out the complete cooling coils. The interlocking of scrap material behind the cooling pipes can be largely avoided by vertically running cooling pipes, **figure 3.**

The lifetime of the cooling panels is primarily determined by *thermal stress.* On the one hand, cooling pipes are subjected to high radiation temperatures on the inner side of the furnace, on the other hand, especially with electric steelmaking, strong thermal shock stress, repeated heating up during melt-down and the cooling down of the panels during charging mean a big problem in regard to the service life of the panels. There is a direct relationship between the life of the cooling pipe and the heat transport: the better the heat transport into the cooling medium, the less the thermal load on the pipework. The aims of the layout criterions are the formation of heat insulating surfaces for decreasing the heat load as well as the best possible heat transmission to the cooling medium. The following influencing factors lead to an optimized panel construction.

Protective slag layer. With a heat conductance of appr. 0.12 to 0.13 W/mK slag is the ideal heat insulator in view of the energetic situation of the total plant and also for the protection of the cooling panels. Constructionally, it is to be ensured that a surface enabling good adherence of the foaming slag is created. Best experience has been gathered here by using a pipe-bar-pipe construction cased with flat material on the back. The slag builds up between the pipes, evenly covering the pipe surfaces (figure 3). Additional slag bolts improve this process such that the arising slag layer becomes so solid that it is not destroyed when the inside of the furnace cools down. Slag holders in the form of plates or bolts have to be welded on the outside of the furnace, welded seams in the area of radiation are to be minimized. Figure 3 shows a proven solution.

Wall thickness. Determinative factors for the heat transition coefficient k are heat transmission coefficients at the boundary surfaces, the thermal conduction coefficient of the cooling pipe material and the wall thickness. The thicker the tube wall, the worse the heat transition coefficient k.

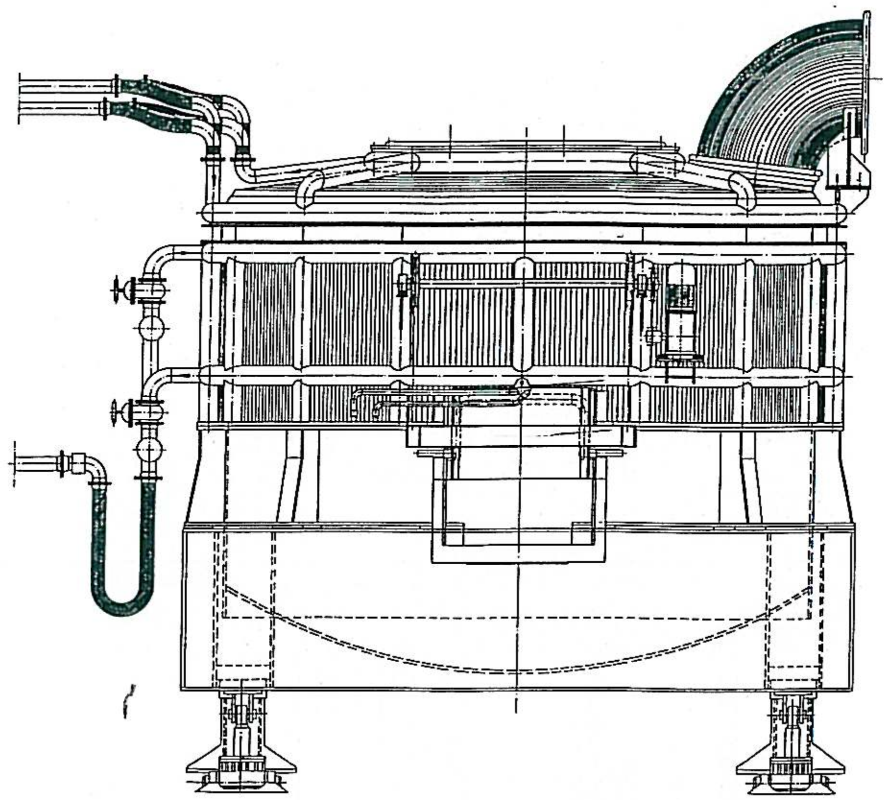

Figure 1. Electric furnace vessel with removable water-cooled upper part and roof

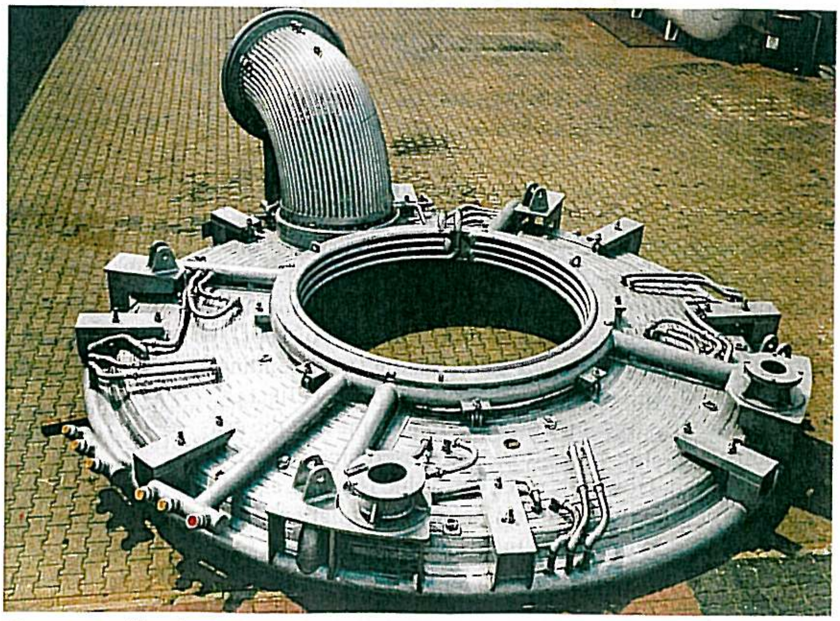

Figure 2. Electric furnace roof with supporting structure and easily replaceable cooling panels

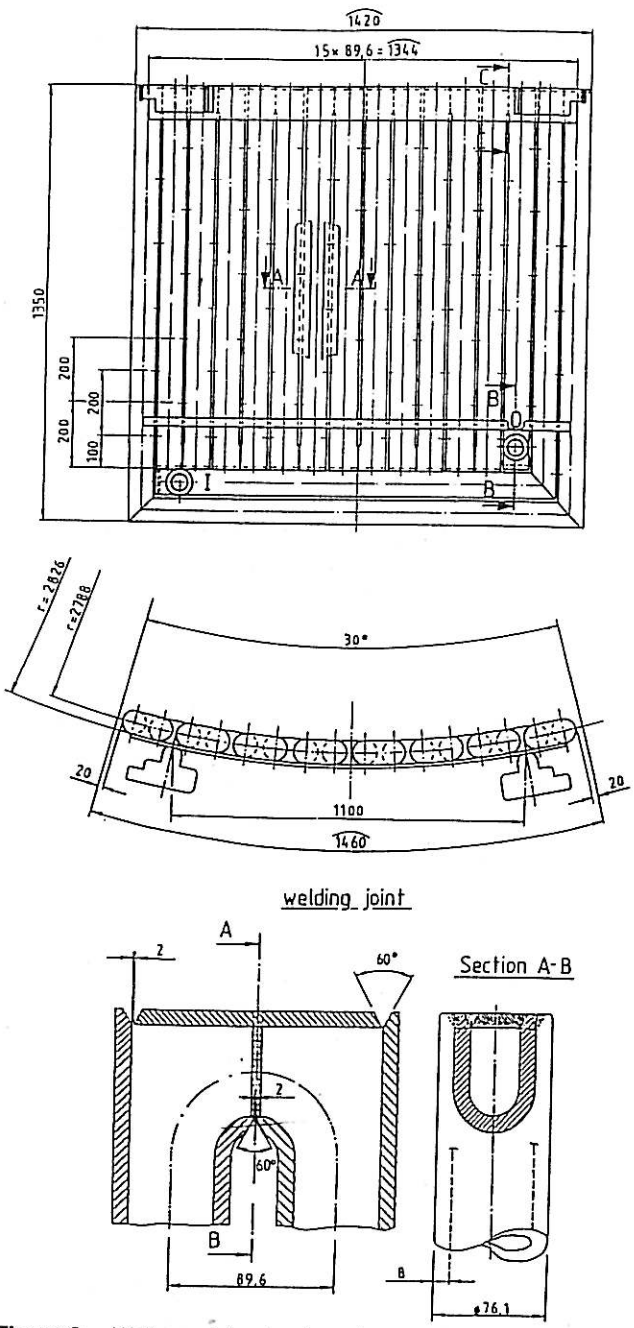

Figure 3. Wall panel in pipe-bar-pipe construction, vertically coiled with improved slag adherence

This means that the temperature difference across the tube wall (radiation side/cooling water side) rises, **figure 4.**

These temperature differences lead to a distribution of stresses across the tube wall as shown in figure 4. This is in addition to residual stresses from necessary welding of the cooling pipe (circumferential seams, bypassing of caps) as well as residual stresses from cold forming (cold bending). **Figure 5** clearly shows the arising superimposing effects.

In practice it is first and foremost important that the critical coefficient – the yield stress of the used pipe material – is not exceeded. However, when this value is in fact exceeded, plastic deformations (upsetting) on the radiation side of the pipe will occur and the material will not return to its original form after cooling down. By the permanent repetition of this process the well-known transverse cracks on the pipe surface will develop and the cooling panel will have to be replaced. Permanent thermal shock stress of the cooling pipes further leads to yield stress changes. With the service time advancing the elasticity of the material deteriorates. This is called artificial aging. The layout has to be made in such a way that the non-required elastic extension area is kept as large as possible.

The wall thickness has a decisive influence on it, minimal material thickness, however, being dependent on the mechanical load on the cooling pipes. The optimized thickness is approx. 8 mm.

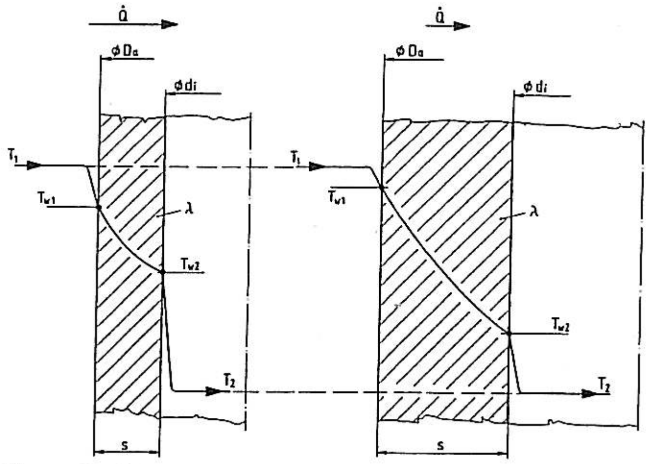

Figure 4. Influence of wall thickness on heat transmission/thermal stress of pipes ($\dot{Q}$ = heat transmission, D, d = diameter, T = temperature, s = pipe wall thickness)

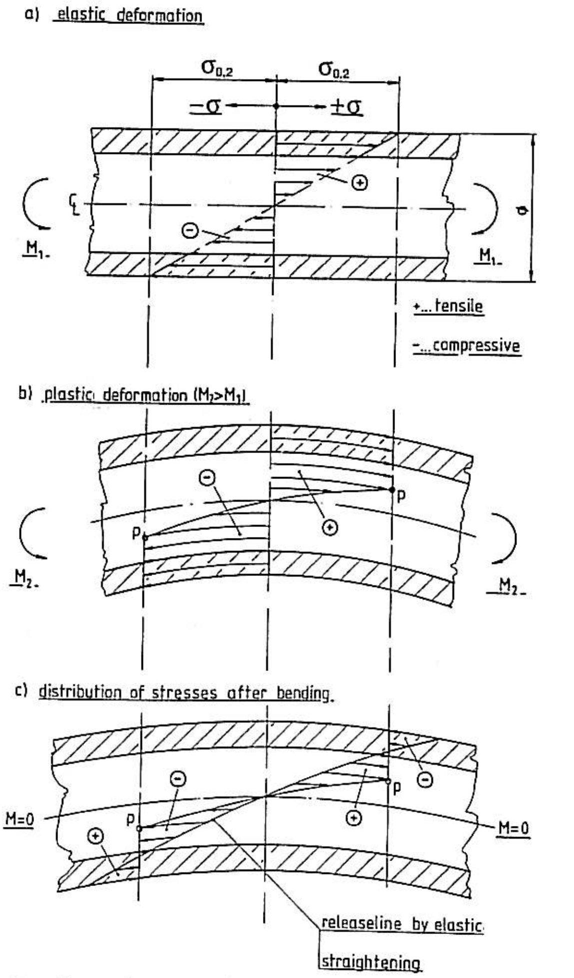

Figure 5. Sum of stresses from cold forming and heat effects

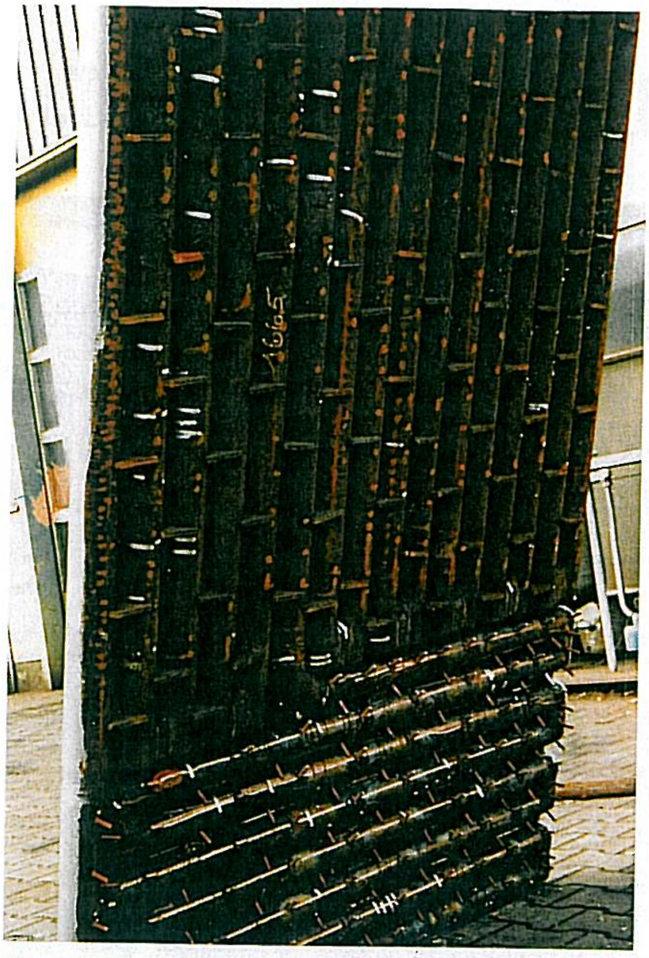

Figure 6. Copper panels for most radiation-intensive areas

Materials. The question about the optimal cooling pipe material can not be answered without considering the economical side. In most applications boiler tubes are used (e.g. Rst 35.8 according to DIN 17175) which are characterized by a favourable price, easy handling and good thermal conduction coefficient (approx. 50 W/mK).

In cases with heat current densities greater than 7 × 10.6 kJ/m^{2}h materials with clearly higher thermal conduction coefficient must be used. In spite of the high price the application of copper pipes has been successful. The thermal conduction coefficient of 383 W/mK allows a maximum permissible heat current density of approx. 21 × 10 × 6 kJ/m^{2}h. Due to the strong heat flows into the cooling water, the areas laid out in copper are to be minimized, limiting the use of copper basically to the highly loaded areas near the liquid steel level, **figure 6.**

Cooling medium and pipe dimensions. The temperature, the flow volume, flow speed and the pressure loss are determining parameters for the constructional layout of the cooling panels. The combination of these factors makes for optimal heat transport out of the cooling pipe, **figure 7.**

Depending on the heat quantity to be removed (see above) the minimum cooling water quantity is determined by the possible temperature increase of the cooling water (at 20 K 1 m^3/h cooling water removes Q = 20000 kcal/h).

A precondition for this is a sufficient flow speed w of the cooling water in order to produce a reliable turbulent flow inside the cooling pipe. **Figure 8** shows the area determinant for us, the aim being a *flow speed* of w > 1.2 m/s.

Taking these values as a basis, pipe diameters between 70 and 90 mm and wall thicknesses of approx. 8 mm have been determined, and supported by much practical experience, as optimal cooling pipe dimensions. ■

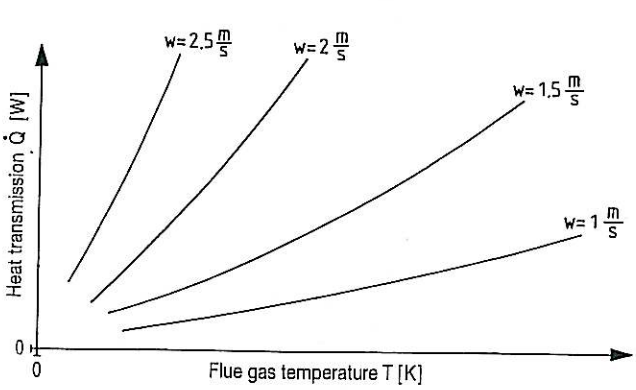

Figure 7. Relationship between heat transmission, cooling medium and flue gas temperatures

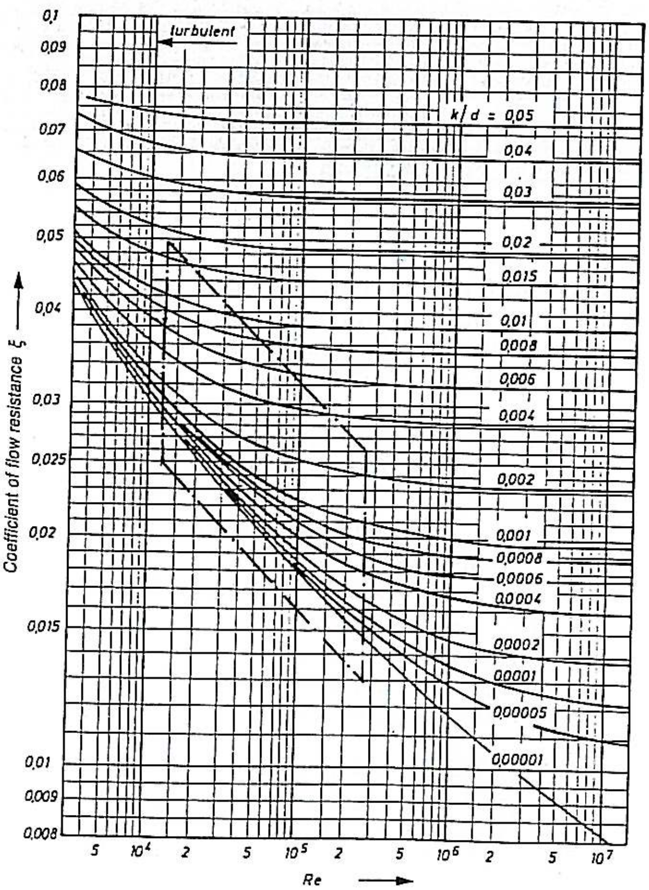

Figure 8. Coefficient of flow resistance during flow inside the pipes, used area