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Recommendation for the Protection of RECOVERY BOILERS 1978

Finnish Recovery Boiler Committee
Corrosion Subcommittee

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PREFACE

The Recommendation for Protection of Boiler Tubes was originally published in 1968 during the first term of the Finnish Boiler Committee. Since then it has been revised several times.

The recommendation is to be used for the selection of materials and protection methods when building new boilers or repairing existing units.

The recommendation is applicable to the furnace of a recovery boiler, especially the lower part, where serious corrosion has been a problem since 1960. The superheater elements are also being studied. However, since the test tubes were installed during 1975, the operation time is still very short. For this reason the subcommittee does not yet wish to include the superheater in this recommendation.

The following persons participated in the Corrosion Subcommittee work during the latest period:

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The Corrosion Subcommittee wishes to thank all those who have helped in the collection of the information contained in this recommendation, especially *L. Mykkänen* and *S. Welsby* from A. Ahlström Osakeyhtiö who have completed the specification for composite tubes.

Please state the origin of any information taken from this publication.

Recommendation for the Protection of

RECOVERY BOILERS 1978

1. *Recommendation for Protection*

The protection periods are stated with reference to normal kraft liquor and to a boiler drum pressure range of 50...100 bar (700...1 300 psi).

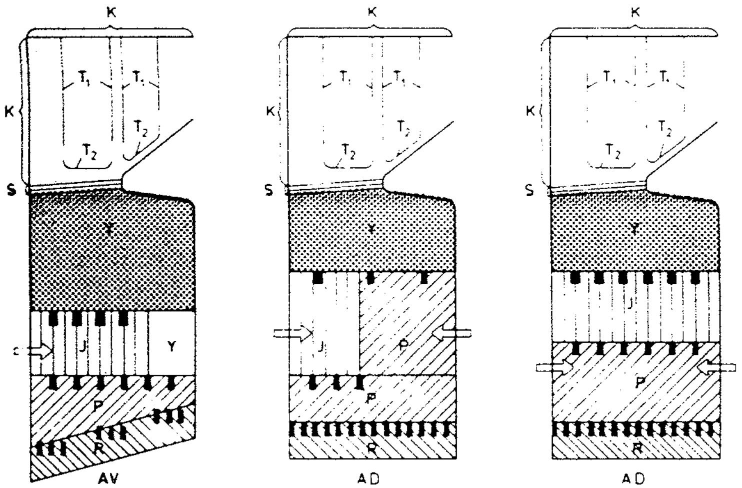
Protection Method	Boiler Zone							
	AD	AV	R	P	J	Y	K	S
Composite tubes	**>20**	**>20**	**>20**	**>20**	**>20**	–	–	–
Carbon steel tubes								
– Austenitic clad welding	–	–	~10	~10	>10	–	–	–
– Tight studding (without repairs)	~20	~6	3...6	3...6	3...6	–	–	–
– 17% Cr-steel flame spraying	–	–	<1	<1	1...3	3...6	–	–
– Metcoloy 405/5 flame spraying	–	–	<1	<1	1...3	3...6	–	–
– 2 mm (.08") corrosion allowance	~20	3...6	1...3	3...6	3...6	~10	**~20**	>10
– 4 mm (.16") corrosion allowance	>20	6...10	2...5	6...10	6...10	**~20**	>20	**~20**

Recommended protection method is indicated with a circle.

The numbers mean protection period expressed in years which has been practically verified or estimated. – = protection unnecessary.

AD	= decanting bottom
AV	= sloping bottom
R	= reduction zone
P	= burning zone
J	= afterburning zone
Y	= upper zone
K	= superheater zone (furnace walls)
S	= water cooled screen

2. *Zones in the Main Types of Recovery Boilers*



BW-type CE-type T-type

3. *Specification for Composite Tubes*

3.1 *Definition*

Composite tubes are tubes made from two different materials, an inner tube and an outer tube. The outer tube is made from austenitic stainless steel SIS 2333, nominal thickness 1.5 mm. The inner surface (backing tube) is made from carbon steel. The tubes are produced by the hot extrusion method, a metallurgical bond is formed between the two materials as a result of the high extrusion temperature and pressure.

In accordance with Finnish Standard SFS 2611 tube wall thickness can be up to 6.3 mm without the need to make separate thermal stress calculations. When the outer and inner materials have different thermal expansion coefficients, calculations cannot be made by using e.g. AD Merkblatt B10, Lorenz formula. If the authorities require calculations they must be made by using special computer programmes.

3.2 *Application*

This recommendation deals with the factors to be taken into consideration when purchasing, welding or manipulating composite tubes.

3.3 *Mechanical and Technical Properties to be Specified when Purchasing Tubes*

3.3.1 The mechanical and technical properties must be tested and examined at least to the same extent as the equivalent properties for normal seamless tubes. In addition the following special requirements must be observed:

- The tensile test is to be performed on the finished composite tube (outer and backing tube together). The extent of the test is to be, at least, to the requirements of DIN 17175.

- Ring tests (ring expanding test) are to be performed on samples taken from both ends of every tube. The method and requirements are to be in accordance with DIN 17175.

- The thickness of the outer component shall be checked from the samples taken for the ring tests, or automatically during the manufacturing process by equipment that continuously measures the thickness of the outer layer.

- The metallurgical bond between the outer layer and the backing tube shall be checked ultrasonically, using as a reference a similar composite tube of the same diameter. The reference tube is to be drilled or milled, from the inside, as far as the interface, with a flat bottomed hole or groove. The size of the hole or groove, the inspection method and the acceptance standard are to be agreed upon separately when placing the order.

- Ultrasonic testing for the detection or longitudinal discontinuities shall be performed in accordance with »Stahl-Eisen Pruefblatt 1915–77» or equivalent.

- Ladle analysis of both the outer tube and backing tube shall be made.

- Ultrasonic testing can be considered to replace the hydrostatic tests required in the standards.

- Other requirements than those mentioned in sections above, required by alternative standards or the export country's pressure vessel regulations, are to be agreed upon separately at the time of purchasing.

In specifying the extent and methods of testing and examination any special requirements of the country to which the recovery boiler is being exported, must be observed.

3.4 *Condition of Delivery*

3.4.1 The tubes shall be delivered in the heat treated condition, such that both the outer tube and backing tube attain the optimum corrosion resistance and mechanical strength properties. The tubes shall be delivered free of scale by pickling or treating in other ways to obtain the same surface quality. For reasons of dimensional accuracy the final treatment can also be cold forming + heat treatment in shielding gas atmosphere or grindling.

3.5 *Tolerances*

Recommended tolerances on length, outer diameter, total wall thickness, outer layer thickness and straightness as follows:

- outside diameter ±1.0 %, min. ±0.5 mm (0.02 in)
- total wall thickness ±10 %
- outer layer thickness ±12.5 % (±15 %)
- length up to and incl. 6000 mm (20 ft) – 0 + 10 mm (3/8 in)
- length over 6000 mm (20 ft) – 0 + 15 mm (5/8 in)
- straightness 1.5 mm/m (0.018 in/ft)

3.6 *Material Certificates*

3.6.1 Test certificates shall, at least, meet the requirements of SFS/3/3B, DIN 50049/3.1B or SIS 11 00 01/A3.

If inspection by a third party inspector is required it must be agreed upon at the time of purchase, and the name of the inspecting authority shall be stated. The certificates shall contain the results of all tests and inspections that have been carried out.

3.7 *Welding Composite Tubes*

3.7.1 Butt Welding

Suitable welding methods are metal arc welding and TIG welding or a combination of both such that the root is welded using TIG welding and the following beads welded by using MIG or metal arc welding. Other welding methods can also be used, if the weld filler material, strength and weld quality are tested by means of procedure tests.

Welding preparations can be as shown in *figures 1...4.*

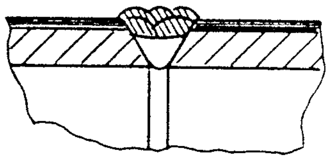


Fig. 1

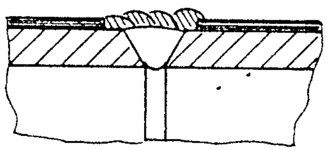


Fig. 2

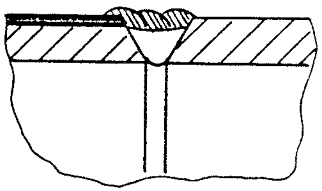


Fig. 3

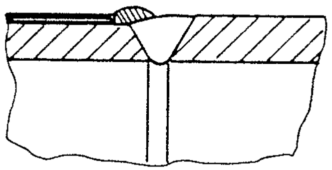


Fig. 4

In *figure 1* the root bead is welded using a filler material suitable to the carbon steel backing tube and the following beads by using an overalloyed filler metal type 24 % Cr and 13 % Ni. (The filler can contain max. 3.0 % Mo.) In *figure 2* the whole of the carbon steel tube is welded by using a filler metal for carbon steel and only the outer layer welded by using the overalloyed filler. When welding the outer layer the weld beads shall not be made by weawing but must be made by overlapping each other in narrow beads.

Weld preparations shown in *figures 3* and *4* can be used when welding composite tubes to carbon steel tubes. The root is welded using carbon steel filler metal and the surface layer or bead using overalloyed filler metal.

3.7.2 Panel Welding

– General

By panel welding is meant the welding of gas tight panel walls made from tubes such that they are welded tightly to each other to form tangential walls or by welding a carbon steel or stainless steel fin between the tubes.

Automatic welding equipment should normally be used in this type of welding. When welding composite tube, penetration of the outer layer shall be avoided.

– Tangential tube walls

MIG or metal arc welding is made in the »natural» weld groove formed between the tubes as in *figure 5.* Submerged arc welding can also be used, in which case it is often necessary to use a stainless steel bar between the tubes, see *figure 6*.

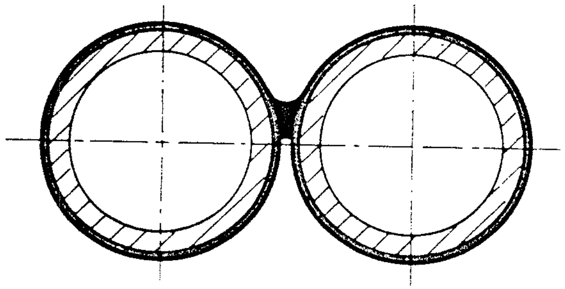


Fig. 5

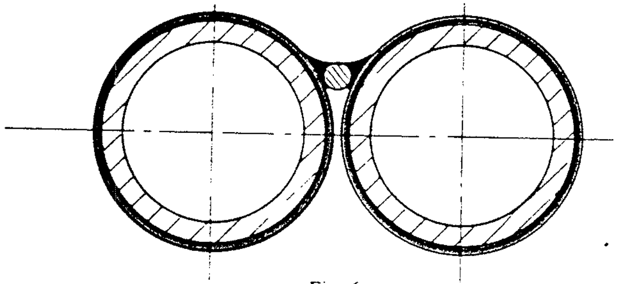


Fig. 6

20 % Cr, 10 % Ni type filler metal is suitable. When selecting filler metals, in addition to the chemical analysis, special attention should be paid to the weld surface properties of the selected filler metal.

Welding is to be performed on the inside (furnace side). In specifying the weld penetration and other weld parameters it is usually necessary to perform welding procedure qualification tests.

Membrane tube walls

Either MIG or submerged arc welding can be used to weld the fins to the tubes. Manual arc welding can be used for short, individual tubes.

Welding shall be performed on both sides of the fin, the allowable unwelded root area is 30 % of the fin's thickness. The sums of the welds' »a»-dimensions, for the same tube, shall be at least 1.25 x fin thickness (as measured from the surface of the weld to the bottom of the penetration) see *figure 7*.

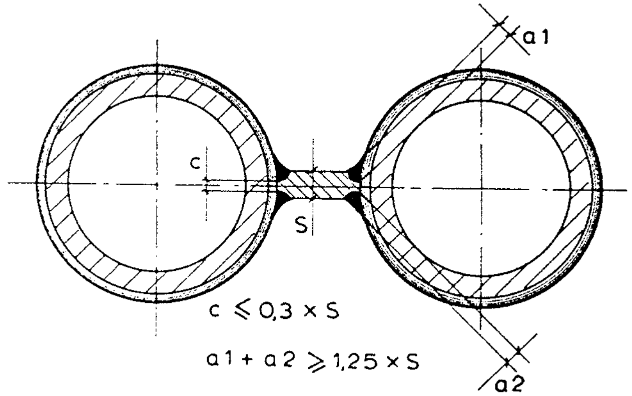


Fig. 7

The fin can be bevelled or unbevelled, depending on the thickness of the material, the required penetration, or on the chemical composition of the weld (e.g. mixing of carbon steel and austenitic weld). If the fin material is carbon steel, high alloy filler metal must be used. If the fin material is austenitic steel, then at least type 18/8 austenitic filler material must be used.

– The same rules as above shall apply when welding other attachments to composite tubes, such as supports, short fins etc.

3.8 *Heat Treatment*

3.8.1 Preheating or postweld heat treatment is not necessary for butt welds or panel welding, nor is it usually recommended on account of the reduction in the corrosion resistance properties of the outer layer.

3.9 *Bending*

3.9.1 The same rules as for carbon steel tubes shall also be observed for composite tubes. However, special attention should be paid to the condition of the bending tools in order to avoid damaging the outer layer with indentations, scratches etc.

The tube manufacturer's recommendations, regarding temperature and cooling must be observed when hot bending composite tubes.

3.10 *Reducing the Tube-ends*

3.10.1 Normal cold forging equipment and presses, developed for carbon steel tubes, can also be used for reducing the ends of composite tubes. In order to avoid damaging the outer layer special attention should be paid to the condition of the tools and the selection of a suitable lubricant. In selecting the degree of reduction it must be noted that heat treatment to reduce the hardness, caused by cold working, cannot in general be made.

3.11 *Welding Inspection*

3.11.1 Butt welds can be inspected by normal x-ray or ultrasonic equipment. The relatively thick wall compared to outer diameter makes it difficult to get an interpretable weld length in the X-ray film when applying the so called ellipse technique. In general apart from individual tubes, one cannot X-ray from two perpendicularly opposite directions such that the result, especially for panel wall tubes would be interpretable. Almost the whole length of the weld can be checked ultrasonically, provided that the distance between the tubes is sufficient and that the unfinned area in the region of the weld is sufficiently long.

3.11.2 Fin and panel welds are inspected visually. In addition, before starting production welding, the panel welding machine's welding parameters should be checked by means of test welds.

4. *Specification for Overlay Welding of Boiler Tubes*

4.1 *Scope*

This specification covers the overlay welding of carbon steel tubes with austenitic stainless steel under shop conditions.

The specification is also applicable to the overlaying of plain carbon steel tubes and tubes protected with studs or metal spraying, installed in operating boilers.

4.2 *Surface Preparation*

Welding may only be carried out on clean surfaces. Under shop conditions new carbon steel tubes are most effectively cleaned by sandblasting.

Under field conditions it is essential to carefully remove solidified smelt, worn studs or old broken metal sprayed coating. Cleaning can be done either by sandblasting or grinding, depending on the individual case.

4.3 *Requirements for Weld Overlaying*

4.3.1 Microstructure

The microstructure of the weld cladding of furnace tubes shall be basically austenitic with about 5...10 % ferrite. The small ferrite content is advantageous for welding, for metallurgical reasons, as it reduces the hot cracking sensitivity of the weld metal.

4.3.2 Chemical Composition

The nominal analysis of the weld cladding should be as follows:

Cr	18...20 %
Ni	10...12 %
Mo	0... 2 %
C_{max}	0.06 %

Chromium and nickel contents may be higher, provided

that the composition of the microstructure specified in chapter 4.3.1 is achieved.

4.3.3 Cladding Thickness

The weld cladding shall be as thin as possible in order to provide good heat transfer and to avoid excessive increase of the total wall thickness. (Thermal stress calculations are, according to standard SFS 2611, required when the wall thickness exceeds 6.3 mm).

To avoid excessive penetration and mixing of the base metal, the layer thickness is limited in manual metal arc welding to about 3 mm minimum with one weld bead using an electrode of 3.25 mm...4 mm diameter. The minimum thickness with inert gas metal arc welding is about 2.5 mm. Maintaining this thickness will control the composition of the overlay weld.

4.4 *Welding Processes and Filler Metals*

4.4.1 Welding Processes

Metal arc welding with a covered electrode is the most usual process for overlay welding in an erected boiler. The use of the inert gas metal arc processes (MIG or TIG) is limited by flowing of the weld pool in the vertical position. By choosing the welding parameters so that the amount of melt is controlled, MIG or TIG methods may also be used.

Under shop conditions, overlay welding may be performed in a flat position. Both metal arc welding and inert gas metal arc processes are very suitable (pulsed arc MIG-technique is especially suited).

4.4.2 Filler Metals

Achievement of the analysis for the weld cladding expressed in chapter 4.3.2 requires the use of overalloyed filler metals, which compensate for base metal dilution and oxidation of the alloy elements. Recommended types of filler metals are preferably low carbon steels (C max ≤ 0.03 %). The following manufacturers' electrodes and filler metals are typical examples:

	Composition, %			
Welding electrodes	C	Cr	Ni	Mo
Avesta P5 (rutile covering)	0.03	22	14	2.7
Bohler Fox CN 23/12 Mo-A	0.03	23	12.5	3.0
Bohler Fox CN 24/13 Nb-A	0.04	24	12.5	+Nb
DEW Thermanit 23/11 E	0.04	22.5	11.0	
Esab OK 67.70	0.04	22	12	3.0
MIG-filler metal fires				
Avesta P5 ... max	0.03	22	14.5	2.7
Sandvik 3 RE 13 ... max	0.025	24	13.0	–

As the layer thickness must be as thin as possible, only single bead welding can be practically applied. The quality of multiple bead welding is better, but it is more expensive. Poor heat transfer in the case of thick weld claddings may develop large temperature differences, which cause severe thermal stresses. These stresses in cyclic thermal conditions may cause tube failures as a result of thermal fatigue.

4.4.3 Welding Parameters

Even when using over-alloyed filler metals it can not be taken for granted that the nominal composition required for the weld cladding is obtained, if the welding parameters (diameter of the filler metal, current, welding speed, oscillation, feeding speed of the wire, etc.) are not verified as suitable for the welding method and filler metal used. To find suitable welding parameters, a welding procedure test is recommended before starting work.

4.4.4 Preheating

Preheating is not necessary in overlay welding.

4.4.5 Welding Procedure Test

A test tube shall be overlay welded in the same welding position (vertical or flat position) as will be used in the actual work. The welding parameters recommended for the welding process and the filler metal shall be used.

The quality of the test weld shall be examined visually and by metallographic examination of the micro-stations.

Examination of the following shall be carried out:

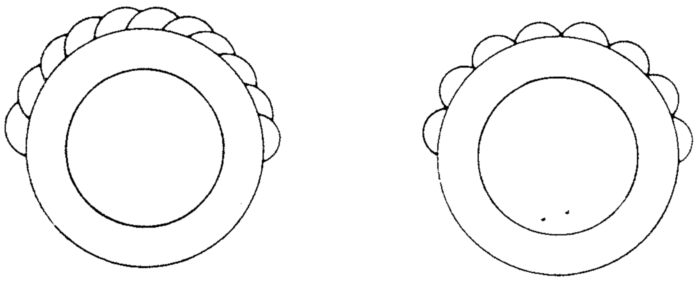
- depth of penetration, layer thickness and bead form
- examination of microstructure and eventual cracks
- measurement of ferrite content either with microsope or with ferrite meter (Permascope, for example)

– hardness measurements of the weld metal and the heat affected zone
– analysis of the overlay welded layer

4.5 *Performance of Welding*

Welding parameters verified with the welding procedure test shall be used in overlay welding. The welders shall be qualified with a welder performance certification test. The sample weld will be examined visually and by layer thickness measurement.

Overlay welding shall be done according to the diagram below so that adjacent beads are melted partly overlapping, which prevents excessive dilution of the joint area.



4.6 *Post Treatment of Weld Cladding*

Grindling of the overlay welded layer and stress-relief annealing are not recommended.

Stress-releaving may be advantageous form the weld deformation point of view, but its effect on corrosion resistance may be disadvantageous.

4.7 *Inspection of Weld Cladding*

Visual examination and ferrite measurement by ferrite meter are the most suitable methods to inspect the weld cladding. The total wall thickness of the tube may also be measured by ultrasonics.

When considered necessary, the inspection of the weld quality may also be carried out with destructive methods by taking a sample from the tube end.

5. *Specification for Tube Studding*

5.1 *Cleaning*

If there is no brick lining in the recovery boiler, a water wash is recommended for furnace cleaning. The soot blowers are used for the initial washing and the last deposits are washed out manually. The best washing results from using the soot blowers is achieved with the water temperature near 100°C (212°F).

5.2 *Studs*

5.2.1 Necessity of Repairs

The studding must be repaired if tube corrosion is suspected. Tube corrosion may begin after the length of the studs has been reduced to below 10 mm (3/8").

5.2.2 Material

Alloy steels are consicered preferable to carbon steel. The best results have been obtained with a steel Werkstoff Nr. 4742 (C max. 0.12 %, Si 1 %, Al 1 %, Cr 18 %).

5.2.3 Dimensions

The most common dimensions for studs are:

Diameter:	10 mm	(3/8")
Length:	20...25 mm	(3/4"...1")

The use of a hollowed-end stud is preferable because it generally adapts to the end configuration of the worn stud.

5.3 *Plastic Refractory*

According to experiments, the use of a refractory does not significantly increase the life of studding. However, refractory on the studded bottom is still recommended.

5.4 *Installation*

Studding as referred to in the Finnish recommendations has always meant tight studding, with triangle spacing of about 20 mm (3/4"). The end of the existing stud is cleaned carefully, as for example by using a grinding wheel. All sharp peaks must be ground smooth. Sandblasting can also be used. When welding on stud extensions one must carefully check to make certain that the existing and new studs are welded together over the whole cross section. No conduction guide is required for the welding gun when using hollowedend studs. However, welding must be performed carefully. The use of porcelain rings is considered unnecessary today. »Cromp-Arc» of Oy AGA Ab is the most common welding gun. The correct welding parameters, current and electric arc time, are determined before starting the work by performing welding tests. The quality of these welds is verified by visual examination and with an impact test, which is made for proving the solidity of the weld.

5.5 *Supervising*

The person supervising the studding work must be thoroughly familiar with stud welding procedures. He also has to have a clearly established area of responsibility. The equipment must be tested and the crew properly trained for the work prior to the shutdown.

6. *Specification for Flame Spraying of Boiler Tubes*

6.1 *Surface Preparation*

6.1.1 Preliminary Cleaning

Preliminary cleaning must be performed if the boiler has been in operation. Preliminary cleaning is best done with a water wash of the entire unit. Washing of the area to be flame sprayed must be performed very carefully. Where a water wash is not possible, the surface can be cleaned mechanically, for example, with an air hammer or a special wire brush.

6.1.2 Sand Blasting

The surface to be flame sprayed must be thoroughly cleaned and roughened to achieve the best possible bond. Roughening media used has to be clean, sharp edged quartz sand or steel grit. Minimum air pressure to be used is 7 bar (100 psi). Blasting sand grain size about 0.1...0.6 mm (0.004...0.024 inches) is used for surface cleaning. Roughening of the cleaned surface is performed with quartz sand with a grain size of about 0.7...1.2 mm (0.03...0.05 inches). Quartz sand cannot be reused. The humidity in the furnace cannot exceed 70 per cent. Air used for sand blasting must be oil-free and dry. The finished surface must be free of oil or humidity.

The class of sand-blasting has to be at least Sa 3, which means blasting until clean metal surface is exposed. All mill scale, rust and other contaminates must be removed. The surface is cleaned following sand blasting with a vacuum cleaner, a clean brush or by blowing with clean, dry air. The prepared metal surface must have a uniform color.

6.1.3 Flame Spraying of Undercoat Layer

The time between sand blasting and the first flame spraying must be the shortest possible, because the completely clean material is easily oxidized. Such oxidation will cause poor bonding of sprayed metal to the base metal surface. The sand blasted surface must be flame sprayed either with the undercoat material or proper spraying metal within four hours of sand blasting. In circumstances where water condenses on the surface to be sprayed, the spraying work

cannot be carried out. The most common material for the undercoat layer, Metco 405, must be sprayed at a distance of about 100...200 mm (4...8 inches). A so called »75 per cent» cover will be reached using about 400 g/m^2 (150 oz/sq ft).

6.2 *Proper Metal Spraying*

6.2.1 Metals Used

17 % Cr-steel has been succesfully used for corrosion protection without undercoat material.

Metcoloy 5 is an austenitic stainless steel (18 Cr, 5 Ni, 8.5 Mn) which withstands corrosion well and which must be furnished with the undercoat layer. Spalling of the sprayed layer has occurred with the procedure in question.

6.2.2 Flame Spraying

When metal is sprayed, the flame must be adjusted in accordance with the given table values. If the flame is oxidizing or carbonifying, spraying speed must be decreased. Spraying speed must be kept sufficiently high. The melting end of the wire must be visible in the air nozzle. The instructions of the sprayer and wire manufacturer must be strictly followed during spraying. Spraying must be performed perpendicular to the projected surface. The lowest layer has to be placed by moving the sprayer vertically. The sprayer is moved at a speed of 0.5...1 m/s (2...3 ft/s). The distance from the sprayer to the surface is to be about 100...200 mm (4...8 inches).

The sprayed metal must be securely bonded and homogenous. Any accumulations or semi-loose metal spatter are not permitted.

6.2.3 Protection Methods and Layer Thicknesses

0.3 mm layer of flame sprayed 17 % Cr-steel (2 400 g/m^2 or 910 oz/sq ft) can be used for the protection of the furnace wall tubes.

Another alternative is:

Layer 1
75 % cover of Metco 405 (400 g/m^2 or 150 oz/sq ft).

Layer 2
ca. 0.3 mm (0.012") Metcoloy 5 (2 400 g/m^2 or 910 oz/sq ft).

6.3 *Inspection and Faults*

6.3.1 Inspection of Preliminary Cleaning

Preliminary cleaning must be inspected and all rough impurities removed before sand blasting.

6.3.2 Inspection of Sand Blasting

No visible oil or humidity is permitted on the sand blasted surface. The roughness and cleanness of the surface are checked by comparison with an approved testing standard. The inspection must be performed carefully, because the

stability of coating is totally dependent upon the cleanness of the surface.

6.3.3 Inspection of Sprayed Metal

The cover produced by the undercoat layer is to be checked by comparison with a testing standard. The average thickness of the sprayed on material is calculated from the amount of wire used. The uniformity of a sprayed layer can be checked with an ultrasonic instrument. Non magnetic layers can be measured with a magnetic meter.

If the layer is too thin, additional metal can be sprayed, provided that the surface is completely dry and there are no visible impurities present.

The bonding of the coating to the tube can be checked with an ultrasonic instrument.

The quality and uniformity of the sprayed surface is to be checked visually. Special attention must be paid to the following aspects during the work:

- readings of the gas flow meters
- spraying distance
- feeding speed of the wire
- spraying angle
- moving speed of the sprayer
- sprayer maintenance service must be done frequently
- the sprayer is to be ignited when directed away from the work surface in order to avoid accumulations and splashes

6.3.4 Common Spraying Faults:

- The most common reasons for bond failure of the coating are: Too slow moving speed of the sprayer, spraying on a dirty surface, inadequate roughness of the surface of incomplete melting of the wire.
- Oil in the compressed air supply prevents the proper bonding of the coating.
- Poor spraying effect can be caused by: Low air pressure, improper balancing of gas pressures, fluctuations of the wire feeding speed or poor conditions of the wire and air nozzle.
- Usual causes for roughness of the coating are: Too high feeding speed, incomplete melting of the wire or irregular burning in the spraying gun.

6.4 *Repairing Flame Sprayed Coating*

6.4.1 Inspection

The period between inspections is determined by the local circumstances. Cleaning of the surface to be inspected can be performed according to item 6.1.1. However, one has to be careful that the coating is not damaged.

6.4.2 Repairs

If it is necessary to sand-blast areas for inspection, the sand-blasted areas must be remetallized. If existing sprayed

metal remains, its removal by sandblasting is often very difficult and repairs are to be limited to areas where sprayed metal has been nearly totally lost.

Flame spraying in repairs is carried out as previously explained.

The correct moment for the repairs of 17 % Cr-steel flame spraying is easier to determine than that for Metcoloy 5 flame spraying because the 17 % Cr-steel layer corrodes evenly. Metcoloy 5 often spalls sporadically. The failed Metcoloy 5 flame spraying may be partially or totally lost. The use of the undercoat material depends in this case on how it is interpreted.