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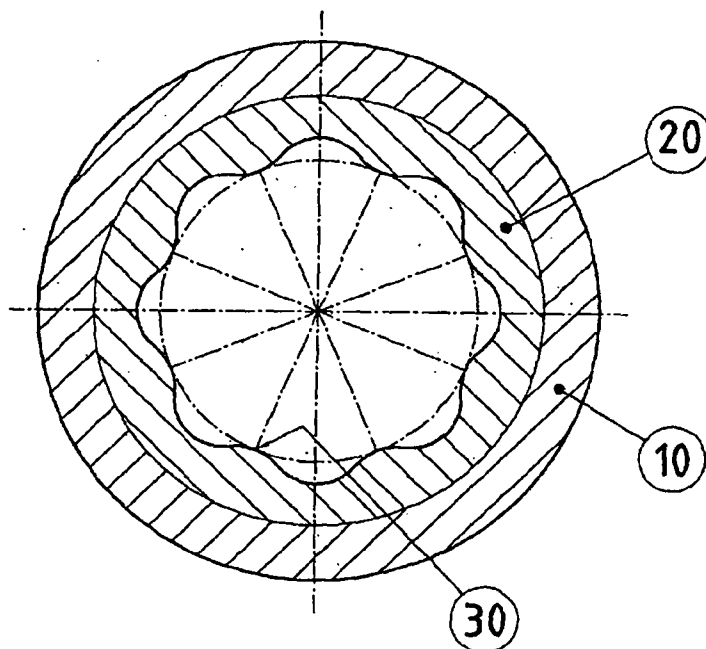
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(54) Title: COMPOSITE TUBE, METHOD OF PRODUCTION FOR A COMPOSITE TUBE AND USE OF A COMPOSITE TUBE

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(57) Abstract: The invention relates to a tube which is particularly well adapted to the special requirements for use in fields such as hydropyrolysis. The inventive tube comprises a first partial tube and a second partial tube. One partial tube is arranged inside the other partial tube. The first partial tube is a spin cast tube and the second partial tube is produced by compression treatment from a powder.

[Fortsetzung auf der nächsten Seite]

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"Composite tube, method of production for a composite tube, and use of a composite tube"

The invention relates to a composite tube, to a process
5 for producing a composite tube and to uses of a composite tube.

Tube furnaces in which a hydrocarbon/steam mixture is passed through a series of individual or meandering
10 tubes (cracking tube coils) at temperatures of above 750°C made from heat-resistant chromium-nickel-steel alloy with a high resistance to oxidation or scaling in flue gases and a high resistance to carburization have proven suitable for the high-temperature pyrolysis of
15 hydrocarbons (crude oil derivatives). The tube coils comprise, for example, vertically running, straight tube sections which are connected to one another via U-shaped tube bends; they are usually heated with the aid of side-wall burners and in some cases also with
20 the aid of bottom burners and therefore have what is known as a light side, facing the burners, and what is known as a dark side, which is offset by 90° with respect thereto, i.e. runs in the direction of the rows of tubes. The mean tube metal temperatures (TMT) are in
25 some cases over 1000°C.

The service life of the cracking tubes is dependent to a very significant extent on their carburization resistance and this in turn is dependent on the coking
30 rate. A crucial factor for the coking rate, i.e. the growth of a layer of carbon deposits (pyrolysis coke) on the tube inner wall is, in addition to the type of hydrocarbons used, the cracking gas temperature in the region of the inner wall and what is known as the
35 operating severity, which conceals the influence of the system pressure and the residence time in the tube system on the ethylene yield. The operating severity is set on the basis of the mean outlet temperature of the cracking gases (e.g. 850°C). The higher the gas

temperature in the vicinity of the tube inner wall above this temperature, the more extensive the growth of the layer of pyrolysis coke becomes, and the insulating action of this layer allows the tube metal

5 temperature to increase still further. Although the chromium-nickel-steel alloys containing 0.4% of carbon, over 25% of chromium and over 20% of nickel, for example 35% of chromium, 45% of nickel and if appropriate 1% of niobium, that are used as tube

10 material have a high resistance to carburization, and carbon diffuses into the tube wall at defects in the oxide layer, where it leads to considerable carburization, which can amount to carbon contents of from 1% to 3% at wall depths of 0.5 to 3 mm. This is

15 associated with considerable embrittlement of the tube material, with the risk of crack formation in the event of fluctuating thermal loads, in particular when the furnace is being started up and shut down.

20 To break down the carbon deposits (coking) on the tube inner wall, it is necessary for cracking operation to be interrupted from time to time and for the pyrolysis coke to be burnt with the aid of a steam/air mixture. This requires operation to be interrupted for up to

25 36 hours, and therefore has a considerable adverse effect on the economics of the process.

British patent 969 796 has disclosed the use of cracking tubes with inner fins. Although inner fins of

30 this type result in an internal surface area which is a good per cent, for example 10%, larger, with a corresponding improvement in the heat transfer, they are also associated with the drawback of a considerably increased pressure loss compared to a smooth tube, on

35 account of friction at the enlarged tube inner surface. The higher pressure loss requires a higher system pressure and therefore has an adverse effect on the yield. An additional factor is that known tube materials with high carbon and chromium contents can no

longer be profiled by cold-working, for example cold-pressing. They have the drawback that their deformability decreases greatly as the hot strength and the resistance to carburization and oxidation increase.

5 This has led to the high tube metal temperatures of, for example, up to 1050°C, which are desirable with regard to the ethylene yield, requiring the use of centrifugally cast tubes.

10 In centrifugal casting, the molten alloy is cast into the end of a tubular casting mould which rotates at such a high velocity that the molten alloy forms a layer of liquid alloy on the inner side of the casting mould. After the alloy has solidified, the rotation of
15 the casting mould is stopped and the tube which has been formed in this way can be ejected. The tube is drilled out over its length in order to have the required internal diameter. Any oxide impurities will always be lighter than the alloy and will therefore
20 "float" on the inside of the tube, with the result that they are removed by the drilling.

However, since centrifugally cast tubes can only be produced with cylindrical walls, a special cutting or
25 electrolytically material-removing machining operation is required to produce an internally finned tube.

European patent EP 0 980 729 B1 describes this type of electrolytic machining of a centrifugally cast tube.

30 For this purpose, the tube blank is introduced in to a holding device which is sealed all the way around at its open ends. The sealing only allows an electrolyte to flow in and out and an electrode bar, which has an electrode attached to its end, to pass through; the
35 electrode can be moved by means of the electrode bar along the inside of the tube to be machined, in the axial direction of the tube. On its outer surface, the electrode has a series of peaks and valleys. The material of the inner side of the tube is

- electrolytically removed by a voltage difference being applied between the electrode and the tube via electrical terminals, which are arranged spaced apart along the tube, and via a current connection block at the end of the electrode bar. In this way, the tube interior is provided with a profile of the geometric shape of the outer surface of the electrode. However, this process has proven complex to carry out.
- 10 The production of composite tubes by centrifugal casting, with the part-tubes produced in separate machining steps and being metallurgically joined to one another, is known from US 6,406,800 B1, which describes a tube bend for pipelines for transporting solids. The composite tube used as the starting product for the bent tube is produced by centrifugal casting. First of all, the material which forms the outer tube is poured in the molten state into the casting mould, which rotates at a high speed, so that the molten alloy forms a layer of liquid alloy on the inside of the casting mould. Shortly before the alloy completely solidifies or immediately after complete solidification, the molten alloy which forms the inner tube is likewise poured into the rotating casting mould, so that the molten second alloy forms a layer of liquid alloy on the inside of the virtually solidified first alloy. The two materials are mixed in the transition region between outer tube and inner tube and thereby produce a metallurgical join between the two tubes. The alloys described in US 6,406,800 B1 are not suitable for use in high-temperature pyrolysis. A further drawback is that only alloys which are suitable for centrifugal casting can be used for the inner and outer tubes.
- 35 Furthermore, it is known from US 5,069,866 to produce a tube having an outer tube and an inner tube joined to the outer tube by hot isostatic pressing (HIP) from two powders. The austenitic steels or nickel alloys

described in that document, however, are likewise not suitable for use in high-temperature pyrolysis.

In view of this background, the invention is based on the problem of proposing a tube which is particularly well matched to the specific demands imposed in special application areas, such as for example hydropyrolysis. Furthermore, it is intended to propose a process for producing tubes having an inner tube and an outer tube.

This problem is solved by the subject matter of the main claims, while advantageous configurations are given in the subclaims.

The invention is based on the underlying concept of forming a composite tube having a first part-tube and a second part-tube, in which one part-tube is arranged in the other part-tube, the first part-tube is a centrifugally cast tube, and the second part-tube has been produced by pressure treatment from a powder. By combining two part-tubes, it is possible for the tube according to the invention to be specifically matched to the demands imposed in special application areas, such as for example hydropyrolysis.

The second part-tube can be used in particular to improve the corrosion properties, even at temperatures of up to 1200°C, the wear resistance, the carburization and coking behaviour when used in ethylene crackers and the heat transfer of centrifugally cast tubes.

For use in the conveying of highly corrosive media, it is possible to use a centrifugally cast tube made from a corrosion-resistant material having, for example, limited mechanical properties, while the remainder of the wall thickness is made from a less expensive material with good mechanical properties.

On account of its homogeneous microstructure and the possibility of using chromium-nickel steels, a centrifugally cast tube is particularly suitable for the thermal cracking of hydrocarbons. However, by forming a second part-tube, which is produced from a powder, for example by hot isostatic pressing, it is possible to impart further properties to the centrifugally cast tube which are unattainable by such a tube itself. For example, the second part-tube can be made from materials which are not suitable for a centrifugal casting process but can be produced in powder form. Furthermore, the second part-tube can be provided with a geometry, for example a surface profile, during the pressure treatment of the powder. With pure centrifugally cast tubes, geometries of this type can otherwise only be achieved by complex remachining steps, for example a cutting or electrolytically material-removing remachining operation. The composite tube according to the invention may, however, also have a smooth surface. In this case, the advantages of the wider choice of materials which are made possible by the use of a powder come to the fore. Under certain circumstances, it is also possible to dispense with the expensive further treatment of the centrifugally cast tube, for example the drilling operation, for the centrifugally cast tube to be used in the composite.

A composite tube is to be understood as meaning a tube which, based on its cross section, has at least two regions (part-tubes), which differ from one another by virtue of the way in which they are produced.

A pressure treatment of the powder is to be understood as meaning any compacting of the powder which, if appropriate in combination with heating of the powder, produces a cohesive solid from the powder or a pre-compacted powder. It is particularly preferable for

the second part-tube to be produced by means of hot isostatic pressing (HIP).

5 In a preferred embodiment, the first part-tube is arranged so as to directly adjoin the second part-tube, as seen in the radial direction of the composite tube, and one of its surfaces is fixedly joined to a surface of the second part-tube. However, it is also possible to provide further part-tubes, in particular further
10 centrifugally cast tubes or further part-tubes produced by pressure treatment from a powder. It is in this way possible to produce various layers of a composite tube which have preferred properties for their particular position in the tube cross section.

15 In a preferred embodiment, the second part-tube has a profile, in particular one or more internal fins, the profile may also be an external profile. A profile can be used to influence media flowing inside the composite
20 tube according to the invention or media flowing along the outside of the composite tube, for example by swirling them up. The particularly preferred embodiment with internal fins is eminently suitable for use in a process for the thermal cracking of hydrocarbons in the
25 presence of steam.

Depending on the side of the centrifugally cast tube which is to be provided with the particular properties by the second part-tube (outer side/inner side), it is
30 possible to produce the part-tube inside the first part-tube or surrounding the first part-tube.

A preferred flow profile made up of core flow and swirling flow in the composite tube according to the
35 invention with internal fins can be achieved using a composite tube in which the flank angle of the fins, which are preferably continuous from the start of the tube to the end of the tube, i.e. the outer angle between the fin flanks and the radius of the tube, is

from 16° to 20° , preferably 17.5° to 18.5° ; it is therefore higher than what is known as the venturi angle, i.e. the aperture angle of a venturi nozzle in the direction of flow, which does not usually exceed 15° . A flank angle of this type, in particular in combination with a fin inclination of 20° to 40° , preferably 22.5° to 32.5° , ensures that a more or less continuous turbulent flow which returns to the fin valleys behind the fin flanks, which leads to the formation of undesirable twisters, i.e. closed plaits of turbulence, in the fin valleys, is not produced in the fin valleys. Rather, the turbulence formed in the fin valleys becomes detached from the fin flanks and is taken up by the swirling flow. The swirl energy induced by the fins is therefore substantially retained and is not mostly consumed in the fin valleys. This leads to the tube metal temperature being reduced and made more even and also makes the temperature over the tube cross section more even.

The fins and the fin valleys located between the fins may be designed to be mirror-symmetrical in cross section and adjoin one another or may form a helical line with in each case identical radii of curvature. The flank angle then results between the tangent in the fin valley/fin transition point and the radius of the composite tube. In this case, the fins are relatively shallow; therefore, the fin height, i.e. the radial distance between the fin valleys and the fin peaks, results from the ratio of the fin surface area within the envelope circle and the clear cross section. The ratio should be between 0.06 and 0.01 (preferably between 0.08 and 0.1). Therefore, the fin height increases with increasing diameter, so that the swirling flow is retained in the strength and direction required for the action of the profile.

In other words, the reduction in the clear area, based on a smooth tube with the same diameter as the envelope

circle of the profile, is at most 3%, and is preferably from 1.5% to 2.5%.

A greater flow velocity results in the fin valleys,
5 leading to a self-cleaning effect and therefore to fewer deposits of pyrolysis coke.

Tests have shown that - irrespective of the internal diameter of the tubes - a total of 6 to 20, preferably
10 8 fins are sufficient to achieve the flow profile in accordance with the invention.

In the composite tube with internal fins in accordance with the invention, the ratio of the quotients of the
15 heat transfer coefficients Q_R/Q_0 to the quotient of the pressure losses $\Delta P_R/\Delta P_0$ in the water test, applying and observing the laws of similarity and using the Reynolds numbers determined for a naphtha/steam mixture, is preferably from 1.4 to 1.5, where R denotes a finned
20 tube and 0 denotes a smooth tube.

The superiority of the composite tube according to the invention (profile 3) compared to a smooth tube (profile 0) and a finned tube with axially parallel
25 fins (profile 1), in which the radial distance between the fin valleys and the fin peaks is 4.8 mm, is illustrated by the data in the table below. The finned tubes all had 8 fins and the same envelope circle.

PROFILE	0	1	3
Fluid temp. at 9950 mm in the centre T_m [°C]	843.6	848.1	843.0
Fluid temp. at 9950 mm at the edge T_r [°C]	888.9	894	874.8
Temperature range at 9950 mm $\Delta T = T_r - T_m$ [°C]	45.3	45.9	31.8
Homogeneity factor with respect to the smooth tube $H_t H_t = \Delta T_0 / \Delta T_x$	1	0.9869281	1.4245283
Hydr. diameter d_h [m]	0.0380	0.0326	0.0358
Homogeneity factor with regard to hydr. $\emptyset$ referenced to the smooth tube $H_{t\emptyset} : H_{t\emptyset} = \Delta T_0 > d_x / \Delta T_x > d_0$	1	0.8477193	1.3420556
Classification H:	2	2	1

In the above table, the hydraulic diameter is defined as follows:

$$5 \quad D_{hydr} = 4 \times (\text{clear cross section}) / \text{internal circumference};$$

it preferably corresponds to the internal diameter of a comparable smooth tube and then gives a homogeneity
10 factor of 1.425.

In the water test, the composite tube according to the invention gives a heat transfer (Q_R) which is higher by a factor of 2.56 compared to the smooth tube, with a
15 pressure loss (ΔP_R) which is increased by only a factor of 1.76.

In a preferred embodiment, the first part-tube has an analysis of

Element	% by weight
C	0.1 to 0.5
Cr	20 to 50
Ni	20 to 80
Nb	0 to 2
Si	0 to 3
W	0 to 5
other	0 to 1
Fe	remainder

and it is particularly preferable for the first part-tube to consist of one of the DIN EN 10027 Part 1 materials GX40CrNiSi25-20, GX40NiCrSiNb35-25, 5 GX45NiCrSiNbTi35-25, GX35CrNiSiNb24-24, GX45NiCrSi35-25, GX43NiCrWSi35-25-4, GX10NiCrNb32-20, GX50CrNiSi30-30, G-NiCr28W, G-NiCrCoW, GX45NiCrSiNb45-35, GX13NiCrNb45-35, GX13NiCrNb37-25, GX55NiCrWZr33-30-04. These materials have proven 10 particularly suitable for high-temperature use in processes for the thermal cracking of hydrocarbons.

In a preferred embodiment, the second part-tube consists of the same material as the first part-tube. 15 However, to set particular properties, it is also possible for the second part-tube to consist of a ceramic material, an intermetallic material or an ODS material. Intermetallic materials can be made inert in aggressive atmospheres, while ODS materials allow a 20 good creep rupture strength by using finely dispersed oxides.

The process according to the invention for producing a composite tube provides for a powder to be brought into 25 contact with the inner or outer surface of a centrifugally cast tube, and the powder to be compacted by pressure treatment to form the second part-tube and joined to the centrifugally cast tube, in particular metallurgically. The use of a powder to produce the 30 second part-tube makes it possible to produce the part-

tube from materials or material combinations which are not suitable for centrifugal casting or can only be produced with considerable outlay (e.g. inert atmosphere). Moreover, it is possible to produce tubes
5 which cannot be centrifugally cast on account of their geometry, such as for example an inner tube with a wall thickness of only a few mm. This in particular gives rise to the possibility of adapting the outer or inner surface of a centrifugally cast tube with specific
10 materials to application areas in which the centrifugally cast materials require special protection, for example protection against corrosion or coking.

15 The powder can be sprayed onto the surface of the centrifugally cast tube which the second part-tube is to adjoin. This is particularly advantageously implemented if the centrifugally cast tube is at an elevated temperature. For this purpose, the
20 centrifugally cast tube can either be sprayed with the powder immediately after it has been cast or can be specially reheated for the application of the powder.

It is particularly preferable for the powder to be
25 heated during the production of the composite tube. This can particularly preferably take place at the same time as the pressure treatment, for example by means of the hot isostatic pressing that is particularly preferably employed. However, it is also possible for
30 the heating of the powder to precede the pressure treatment. If the pressure treatment and the heating of the powder are carried out simultaneously, the result is a second part-tube with a high density, a low porosity and good metallurgical bonding.

35

The heating of the powder can be effected by heat transfer from the outside, for example by heating the centrifugally cast tube or by means of a gas stream flowing over the powder or by means of a heating

element which is in contact with the powder. However, it is also possible for the powder to be heated inductively.

5 The powder can be pre-compacted prior to the pressure treatment. This is particularly preferably done by shaking. To improve the handling of the powder, it can be pre-compacted outside the centrifugally cast tube to form a shaped body, for example to form a tube or a
10 cylinder. The pre-compacting can be carried out to a sufficient extent for the shaped body to be suitable for handling, i.e. for example to be self-supporting. The pre-compacted powder in the form of a shaped body is then easy to introduce into the centrifugally cast
15 tube.

The handling properties of the powder can in addition or as an alternative be improved if the powder is bound using a binder, for example to form a shaped body. The
20 binder preferably leaves the powder during the pressure treatment, in particular during a pressure treatment with heating.

It is particularly preferable to produce a composite
25 tube having a second part-tube arranged in the first part-tube by a process in which a core is inserted into a centrifugally cast tube, a clear space which remains between the inner surface of the centrifugally cast tube and the core is filled with a powder, the
30 centrifugally cast tube together with the core and the powder is introduced into a pressure chamber, the pressure chamber is placed under pressure with simultaneous heating of the powder, and after the pressure treatment has concluded, the core is removed
35 from the composite tube produced in this way. The introduction of the powder into a clear space which remains between the inner surface of the centrifugally cast tube and the core has proven advantageous for handling, in particular in the case of a vertically

upright centrifugally cast tube. Depending on the spatial conditions, it is possible for the introduction of the core and/or the filling with the powder to take place while a centrifugally cast tube is already inside
5 a pressure chamber.

It is preferable for a core with a profile that is the inverse of a fin profile to be produced on the inner side of the composite tube to be inserted into the
10 centrifugally cast tube. The composite tube therefore receives a second part-tube with an internal profile which can particularly preferably be used in a process for the thermal cracking of hydrocarbons in the presence of steam.

15

The core can be removed from the composite tube at least in part by means of etching or by mechanical processes. This makes it easy to release the core from the composite tube produced even if the core has in
20 part been metallurgically joined to the second part-tube.

In addition or as an alternative, it is possible for the powder to be provided, on the side facing the core or the mould, with a spacer material, for example a
25 special binder, which prevents metallurgical joining to the core or the mould during the pressure treatment of the powder, in particular during the heating. This is preferably done by evaporating the spacer material at
30 the transition from the powder to the core or to the mould.

To produce a composite tube with the second part-tube provided on the outer side of the centrifugally cast tube, according to a preferred embodiment the
35 centrifugally cast tube is inserted into a mould, a clear space which remains between the outer surface of the centrifugally cast tube and the mould is filled with a powder, the centrifugally cast tube is

introduced into a pressure chamber, the pressure chamber is placed under pressure with simultaneous heating of the powder, and after the pressure treatment has concluded, the composite tube produced in this way
5 using a first part-tube and a second part-tube is removed from the mould.

The powder in the clear space between the core and the centrifugally cast tube or the mould and the
10 centrifugally cast tube can be compacted by shaking.

To improve the handling of a centrifugally cast tube with powder that has been introduced into a clear space between the mould and the centrifugally cast tube or
15 the core and the centrifugally cast tube, the clear space is preferably closed off at one end. This in particular allows handling of a vertically upright tube without the powder dropping out of the clear space.

20 The pressure treatment is carried out in particular at pressures of at least 450 bar, in particular 1000 bar or more. During the heating, the powder is particularly preferably heated to a temperature of at least 450°C, in particular of 1000°C or more.

25 The compacting of the powder during the pressure treatment can be carried out under an inert atmosphere. This in particular prevents oxidation of the powder during the production of the second part-tube. It is
30 particularly preferable for the pressure chamber to be filled with an inert gas.

Particularly efficient production of composite tubes according to the invention can be achieved if a
35 plurality of composite tubes are produced together in one pressure chamber.

In the case of a composite tube that is to be produced with helically running internally finned tubes, the

helical shape can be generated by producing a composite tube with straight fins and then twisting the ends of the composite tube with respect to one another following production.

5

The economics of the thermal cracking of hydrocarbons in tube furnaces with externally heated tubes can be improved by the use of a composite tube, since preferred properties can be set for the particular position of the part-tube by means of the different production forms and materials used for the part-tubes of the composite tube. It is particularly preferable to use a composite tube according to the invention in which the first part-tube is a centrifugally cast tube and the second part-tube has been produced by pressure treatment from a powder.

The composite tube according to the invention can in particular be designed and used in such a manner that a swirling flow is generated in the immediate vicinity of the fins and is converted into a core zone with a predominantly axial flow at increasing radial distance from the fins. The transition between the outer zone with the swirling flow and the core zone with the predominantly axial flow is made gradually, for example exponentially.

In the use according to the invention, the swirling flow takes up the detaching turbulence at the fin flanks, so that the turbulence is not locally recycled into the fin valleys in the form of a continuous circular flow. This is associated with an increase in the mean residence time of 10% to 20%, for example 15%. This is ensured in particular if the swirling flow in the region of the fins or the fins themselves run at an angle of from 20° to 40°, for example up to 32°, preferably 22.5° to 32.5°, with respect to the tube axis.

In the use according to the invention, the supply of heat in the tube wall and in the tube interior, which inevitably differs over the tube circumference between the light side and the dark side, is compensated for and the heat is quickly dissipated inwards to the core zone. This is associated with a reduction in the risk of local overheating of the process gas at the tube wall, with the resultant formation of pyrolysis coke. Moreover, the thermal stressing of the tube material is reduced on account of the temperature compensation between light side and dark side, which lengthens the service life. Finally, in the use according to the invention, the temperature over the tube cross section is also made more even, resulting in a better ethylene yield or operating severity. The reason for this is the reversibility of the cracking reaction, which without the radial temperature compensation according to the invention in the tube interior leads to cracking at the hot tube wall and recombination in the centre of the tube.

Furthermore, a laminar flow layer, which is characteristic of turbulent flows, with a greatly reduced heat transfer is formed in the case of a smooth tube and to a greater extent in the case of fin profiles with an internal circumference which is increased by more than 10%. This laminar flow leads to the increased formation of pyrolysis coke, likewise with a poor thermal conductivity. The two layers together require greater introduction of heat or a higher burner capacity. This increases the tube metal temperature (TMT) and correspondingly shortens the service life.

The swirling flow very considerably reduces the laminar layer; moreover, it is associated with a velocity vector which is directed towards the tube centre and reduces the residence time of cracking radicals or cracking products at the hot tube wall and their

chemical and catalytic conversion into pyrolysis coke. In addition, the temperature differences between fin valleys and fins, which are not inconsiderable in the case of internally profiled tubes with high fins, are compensated for by the swirling flow according to the invention. This increases the time interval between the need to carry out two coke removal operations. A minimal residence time of the cracking products which have a tendency to coke is improved in the case of cracking tubes provided with internal fins. This is particularly important because without the swirling flow according to the invention a not inconsiderable temperature difference results between the fin peaks and the base of the fin valleys.

15

In the use according to the invention, it is preferable for the peripheral velocity of the gas flow in the fin valleys to be greater than at the fin peaks.

20 The diagram presented in Fig. 1 includes a comparison of the swirling or peripheral velocities in a finned tube according to the invention (profile 3) with 8 fins and a fin pitch of 30° and two comparison tubes (profiles 4 and 6), each with a fin pitch of 16° and 3 or 8 fins, respectively, over the tube cross section. The curves clearly demonstrate the significantly higher circumferential velocity in the edge zone of the composite tube according to the invention of at most approximately 2.75 or 3 m/s compared to the maximum velocity of only approximately 1.5 m/s in the edge zones of the two comparison tubes.

The diagram presented in Fig. 2 shows the distribution of the circumferential velocity over the tube radius for the profile 3 of a composite tube according to the invention. The two - coinciding - upper curves were each measured on a radius which ran through a fin valley on the light side and on the dark side, respectively, while the two lower curves were each

measured along the radii which ran through the fin peaks on the light side and dark side, respectively.

Fig. 3 illustrates three test tubes, including their data, in cross section, including the profile 3 according to the invention. The diagrams each indicate the temperature profile across the tube radius on the dark side and the light side. A comparison of the diagrams reveals the lower temperature difference between tube wall and tube centre and the lower tube metal temperature in the case of the profile 3 according to the invention.

The swirling flow produced with the use of the composite tube according to the invention ensures that the fluctuation in the inner-wall temperature over the circumference of the tube, i.e. between the light side and the dark side, is less than 12°C , even though the tube coils, which are customarily arranged in parallel rows, of a tube furnace are heated or acted on by combustion gases with the aid of side wall burners only on opposite sides and the tubes therefore each have a light side, facing the burners, and a dark side, which is offset through 90° with respect thereto. The mean tube metal temperature, i.e. the difference in the tube metal temperature on the light and the dark side, leads to internal stresses and therefore determines the service life of the tubes. Therefore, the reduction in the mean tube metal temperature of a composite tube according to the invention with eight fins with a pitch of 30° , a tube internal diameter of 38.8 mm and tube external diameter of 50.8 mm, i.e. a difference in height between fin valleys and fin peaks of 2 mm, of 11° compared to a smooth tube of the same diameter, based on a mean service life of 5 years, which can be seen from the diagram presented in Fig. 4, results, at an operating temperature of 1050°C , in a calculated increase in service life to approximately 8 years.

The temperature distribution between the light side and the dark side for the three profiles shown in Fig. 3 is to be found in the diagram shown in Fig. 5. The lower temperature level of the temperature curve for the profile 3 compared to the smooth tube (profile 0) and the considerably narrower fluctuation range for the profile 3 curve compared to the profile 1 curve are noticeable.

- 5
- 10 A particularly expedient temperature distribution is established if the isotherms run in circles in the core zone and follow the inner profile of the composite tube only in the swirl zone.
- 15 A more uniform distribution of the temperature over the cross section results in particular if the swirling flow increases by 1.8 to 20 m/s per metre of tube length and if it covers 7% to 8% of the clear cross section, calculated from the entry of the gas mixture
- 20 to the profiled tube.

With the use of the composite tube according to the invention, with a view to achieving a high ethylene yield with a relatively short tube length, the temperature homogeneity factor over the cross section and the temperature homogeneity factor referenced on the hydraulic diameter should be over 1 in relation to the homogeneity factors of a smooth tube. In this context, the homogeneity factors are defined as

25

30 follows:

$$H_{t\emptyset}:H_{t\emptyset} = \Delta T_0 > d_x / \Delta T_x / d_0$$

The composite tube according to the invention can be used particularly successfully in all high-temperature processes, such as those in which the tube, in particular on the outer side, is exposed to high temperatures of, for example, 800 to 1000°C. In particular, the composite tube according to the

35

invention can be used in the production of coloured pigments, in rotary tubular kilns, for example for the combustion of substances from the chemical industry or pharmaceutical industry, or in refuse incineration
5 plants.

Fig. 6 illustrates an exemplary embodiment of the composite tube according to the invention. It has a first part-tube 10 and a second part-tube 20 with fins
10 30 which has been produced by pressure treatment from a powder.

Patent Claims:

1. Composite tube having a first part-tube (10) and a second part-tube (20), in which
 - 5 - one part-tube is arranged in the other part-tube,
 - the first part-tube (10) is a centrifugally cast tube, and
 - the second part-tube (20) has been produced by pressure treatment from a powder.
2. Composite tube according to Claim 1, characterized in that the first part-tube (10) is metallurgically joined to the other part-tube (20).
3. Composite tube according to Claim 1 or 2, characterized in that the second part-tube (20) has a profile.
4. Composite tube according to one of Claims 1 to 3, characterized in that the second part-tube (20) is arranged in the first part-tube (10).
5. Composite tube according to Claim 3 or 4, characterized in that the second part-tube (20) has at least one internal fin (30).
6. Composite tube according to Claim 5, characterized in that the internal fin runs helically.
7. Composite tube according to Claim 5 or 6, characterized in that the flank angle of the fin is from 16 to 20°.
8. Composite tube according to one of Claims 5 to 7, characterized in that the pitch angle of the fin is from 20° to 40°.

9. Composite tube according to one of Claims 5 to 8, characterized in that a plurality of fins and the fin valleys located between the fins are designed to be mirror-symmetrical in cross section.
- 5
10. Composite tube according to one of Claims 5 to 9, characterized in that the fin peaks and the fin valleys of a plurality of fins in each case adjoin one another.
- 10
11. Composite tube according to one of Claims 5 to 10, characterized in that the fins and the fin valleys of a plurality of fins have the same radius of curvature.
- 15
12. Composite tube according to one of Claims 5 to 11, characterized by a total of six to twenty fins.
- 20
13. Composite tube according to one of Claims 5 to 12, characterized in that the ratio of the fin surface area within the profile envelope circle to the clear cross section of the profile is in a range from less than 0.06 to 0.1.
- 25
14. Composite tube according to one of Claims 5 to 13, characterized in that the ratio of the quotients of the heat transfer coefficients Q_R/Q_0 to the quotient of the pressure losses $\Delta P_R/\Delta P_0$ in the water test is from 1.4 to 1.5, where R denotes a composite tube with fins and 0 denotes a smooth tube.
- 30
15. Composite tube according to one of Claims 5 to 14, characterized in that the hydraulic diameter corresponds to the internal tube diameter of a comparable smooth tube.
- 35

16. Composite tube according to one of Claims 1 to 15, characterized in that the first part-tube (10) consists of a material with the analysis

Element	% by weight
C	0.1 to 0.5
Cr	20 to 50
Ni	20 to 80
Nb	0 to 2
Si	0 to 3
W	0 to 5
Others	0 to 1
Fe	Remainder

5

in particular of one of the DIN EN 10027 Part 1 materials GX40CrNiSi25-20, GX40NiCrSiNb35-25, GX45NiCrSiNbTi35-25, GX35CrNiSiNb24-24, GX45NiCrSi35-25, GX43NiCrWSi35-25-4, GX10NiCrNb32-20, 10 GX50CrNiSi30-30, G-NiCr28W, G-NiCrCoW, GX45NiCrSiNb45-35, GX13NiCrNb45-35, GX13NiCrNb37-25, GX55NiCrWZr33-30-04.

- 15 17. Composite tube according to one of Claims 1 to 16, characterized in that the second part-tube is made from the same material as the first part-tube and/or from a ceramic, intermetallic or ODS material.

- 20 18. Process for producing a composite tube according to one of Claims 1 to 17, characterized in that a powder is brought into contact with the inner or outer surface of a centrifugally cast tube, and the powder is compacted by pressure treatment to 25 form the second part-tube and joined to the centrifugally cast tube.

19. Process according to Claim 18, characterized in that the powder is heated.

30

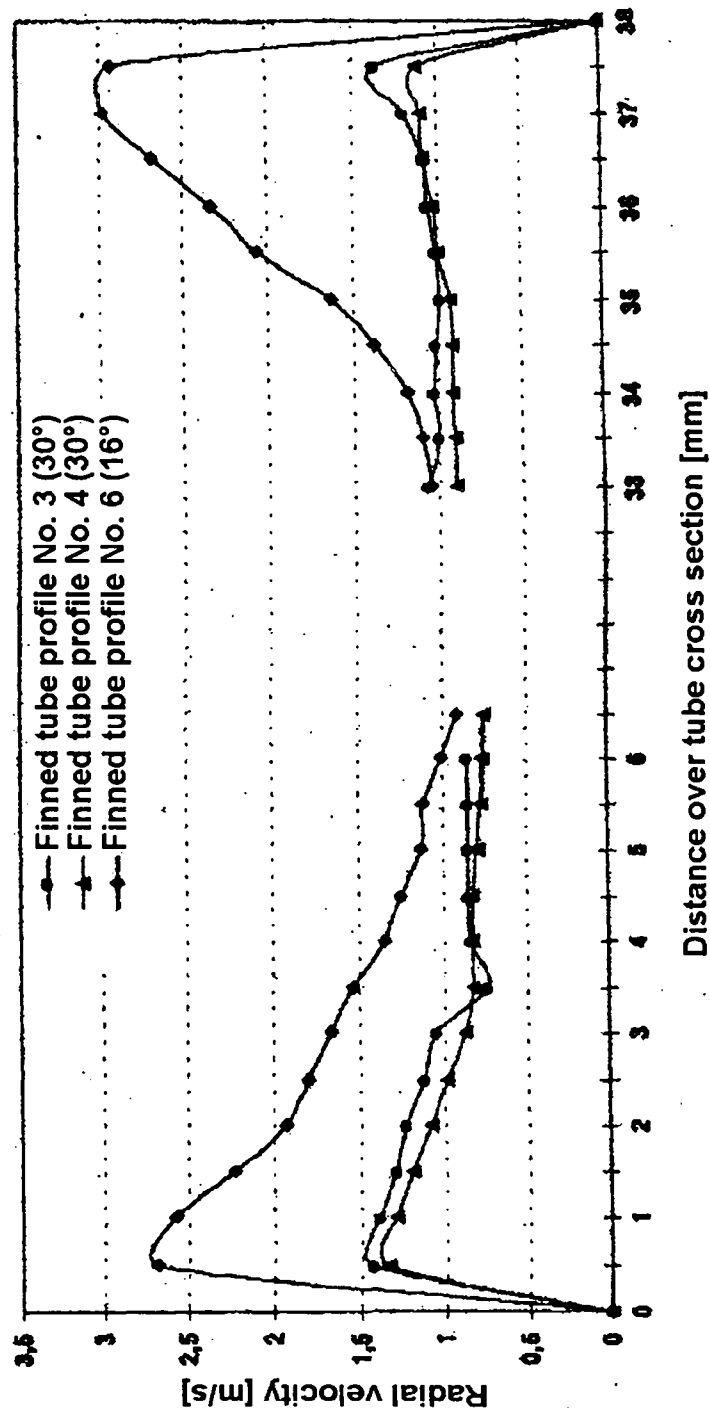
20. Process according to Claim 18 or 19, characterized in that the powder is pre-compacted prior to the pressure treatment.
- 5 21. Process according to Claim 20, characterized in that the powder is pre-compacted by means of shaking.
- 10 22. Process according to one of Claims 19 to 21, characterized in that
- a core is inserted into a centrifugally cast tube
 - a clear space which remains between the inner surface of the centrifugally cast tube and the
 - 15 core is filled with a powder,
 - the centrifugally cast tube is placed under pressure with simultaneous heating of the powder,
 - after the pressure treatment has concluded, the
 - 20 core is removed from the composite tube produced in this way.
23. Process according to Claim 22, characterized in that a core with a fin profile that is the inverse
- 25 of a fin profile to be produced on the inside of the composite tube is inserted into the centrifugally cast tube.
24. Process according to Claim 22 or 23, characterized
- 30 in that the core is removed from the composite tube at least in part by means of etching.
25. Process according to one of Claims 19 to 21, characterized in that
- 35 - a centrifugally cast tube is inserted into a mould,
- a clear space which remains between the outer surface of the centrifugally cast tube and the mould is filled with a powder,

- the centrifugally cast tube is placed under pressure with simultaneous heating of the powder,
 - after the pressure treatment has concluded, the composite tube produced in this way is removed from the mould.
- 5
26. Process according to one of Claims 22 to 25, characterized in that the clear space is closed at at least one end of the tube.
- 10
27. Process according to one of Claims 18 to 26, characterized in that a pressure of at least 450 bar is generated for the pressure treatment.
- 15
28. Process according to one of Claims 19 to 27, characterized in that the powder is heated to a temperature of at least 450°C.
- 20
29. Process according to one of Claims 19 to 28, characterized in that the powder is heated under an inert atmosphere.
- 25
30. Process according to one of Claims 18 to 29, characterized in that the pressure treatment is carried out in an inert atmosphere.
- 30
31. Process according to one of Claims 20 to 30, characterized in that a plurality of tubes are produced in one pressure chamber.
- 35
32. Process according to one of Claims 18 to 31, characterized in that the ends of a composite tube with axially parallel fins produced using a first part-tube and a second part-tube are twisted with respect to one another.
33. Use of a composite tube for the thermal cracking of hydrocarbons in the presence of steam.

34. Use of a composite tube according to one of Claims 1 to 17 for the thermal cracking of hydrocarbons in the presence of steam.
- 5 35. Use of a composite tube according to one of Claims 1 to 17 for the thermal cracking of hydrocarbons in the presence of steam, in which the charge mixture is passed through externally heated tubes with helical internal fins, characterized in that
10 a swirling flow is generated in the immediate vicinity of the fins and is converted into a core zone with a predominantly axial flow at increasing radial distance from the fins.
- 15 36. Use according to Claim 35, characterized in that the swirling flow takes up the detaching turbulence at the fin flanks.
- 20 37. Use according to Claim 35 or 36, characterized in that the circumferential velocity of the gas flow in the fin valleys is greater than at the fin peaks.
- 25 38. Use according to one of Claims 35 to 37, characterized in that the swirling flow at the fins runs at an angle of 20° to 40° , preferably of 22.5 to 32.5° , with respect to the tube axis.
- 30 39. Use according to one of Claims 35 to 38, characterized in that the fluctuation in the inner-wall temperature over the circumference of the tube is less than 12°C .
- 35 40. Use according to one of Claims 35 to 39, characterized in that the isotherms in the core zone are circular.
41. Use according to one of Claims 35 to 40, characterized in that the velocity of the swirling

flow increases by 1.8 to 2.0 m/s per metre of tube length.

- 5 42. Use according to one of Claims 35 to 41, characterized in that the velocity of the swirling flow covers 7% to 8% of the clear cross section per meter of tube length.
- 10 43. Use according to one of Claims 35 to 42, characterized in that the temperature homogeneity factor over the cross section and the temperature homogeneity factor referenced on the hydraulic diameter is over 1 in relation to the homogeneity factors of a smooth tube.
- 15 44. Use of a composite tube according to one of Claims 1 to 17 in high-temperature applications, in particular in a rotary tubular kiln or a refuse incineration plant.



Radial velocities in profiles
with inclination with respect to the tube axis

Fig. 1

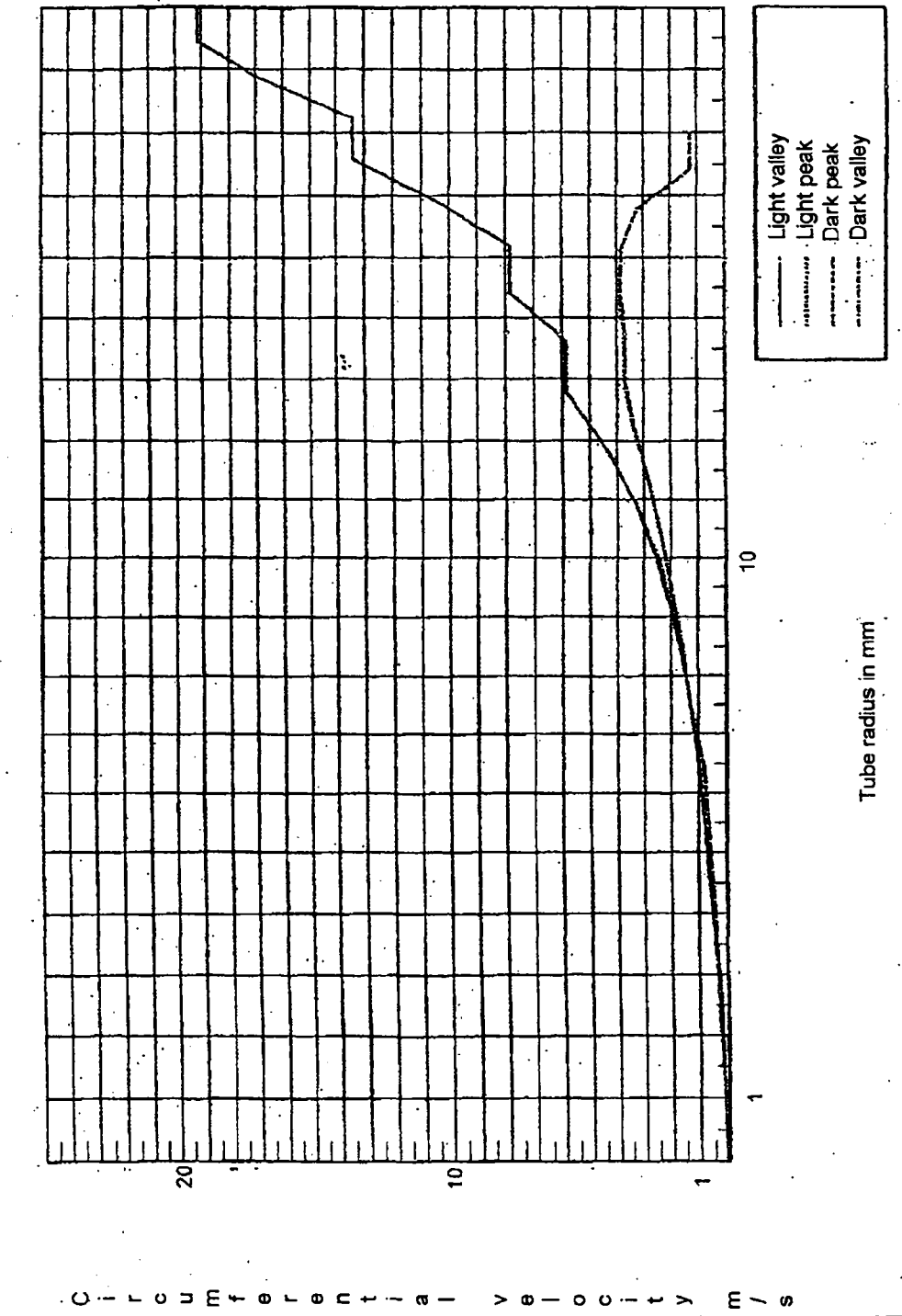
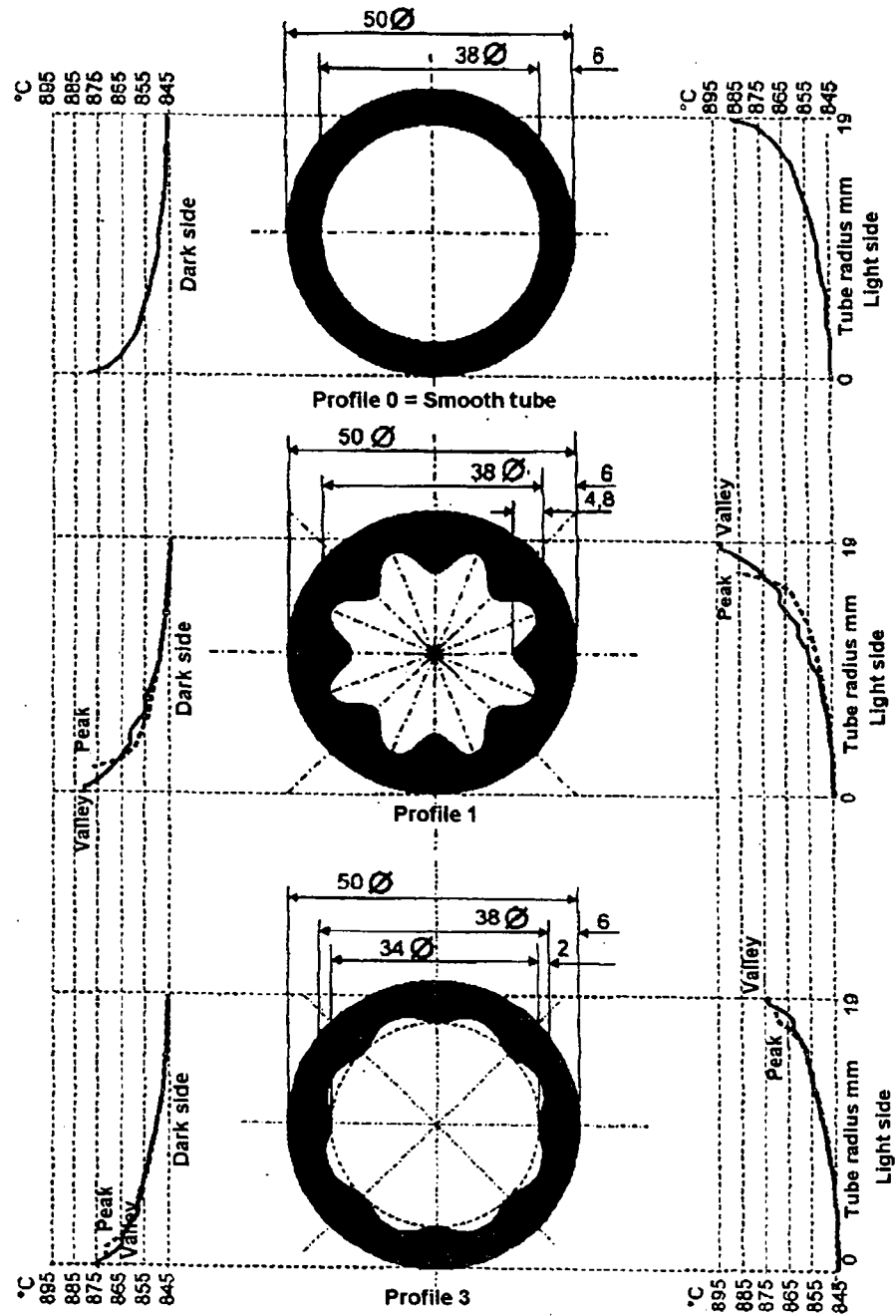


Fig. 2



Profile shapes
with temperature profile in the fluid (naphtha)
at 9950 mm plotted over a radius in the tube,
peak = profile peak, valley = profile valley

Fig. 3

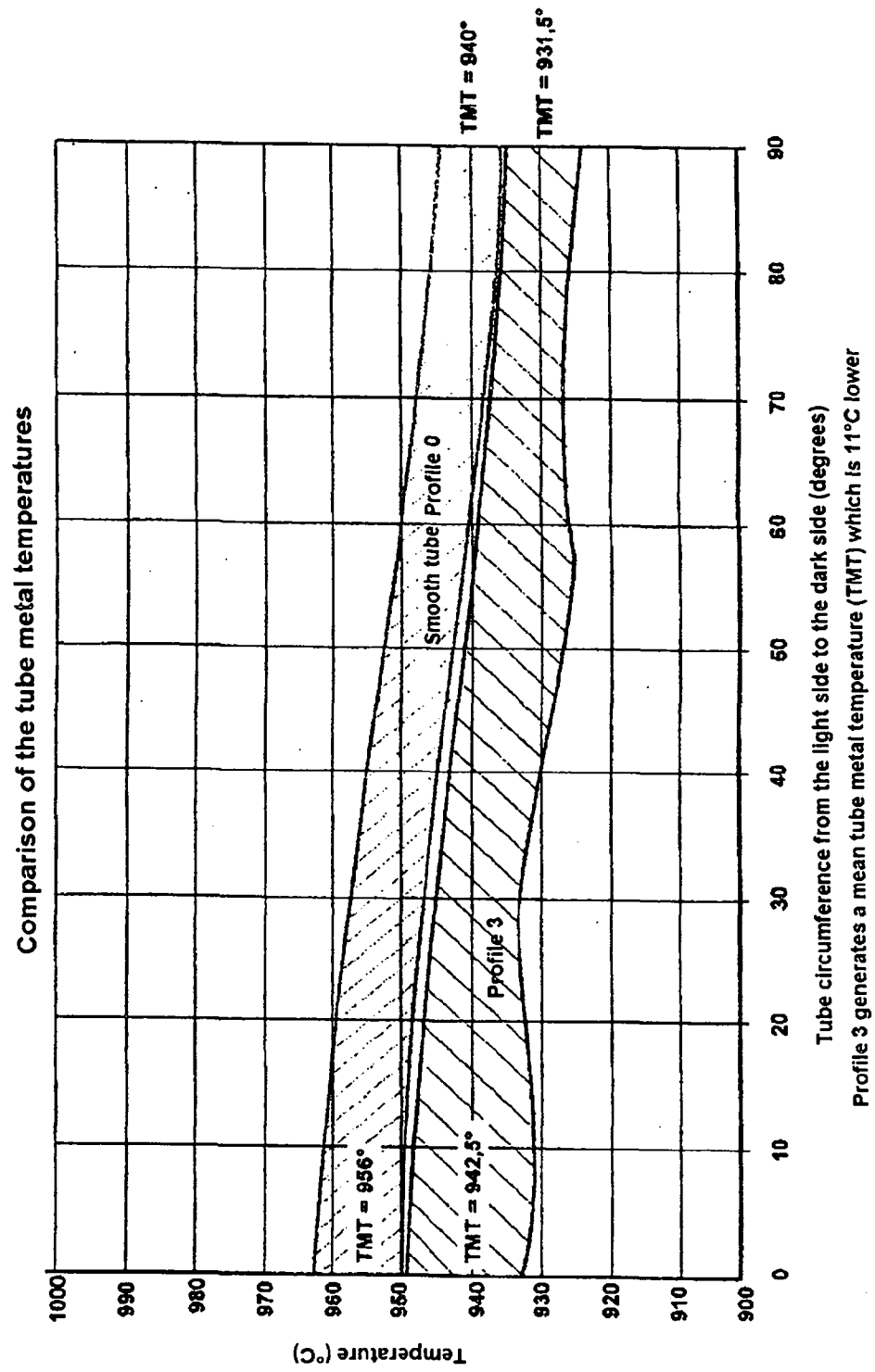


Fig. 4

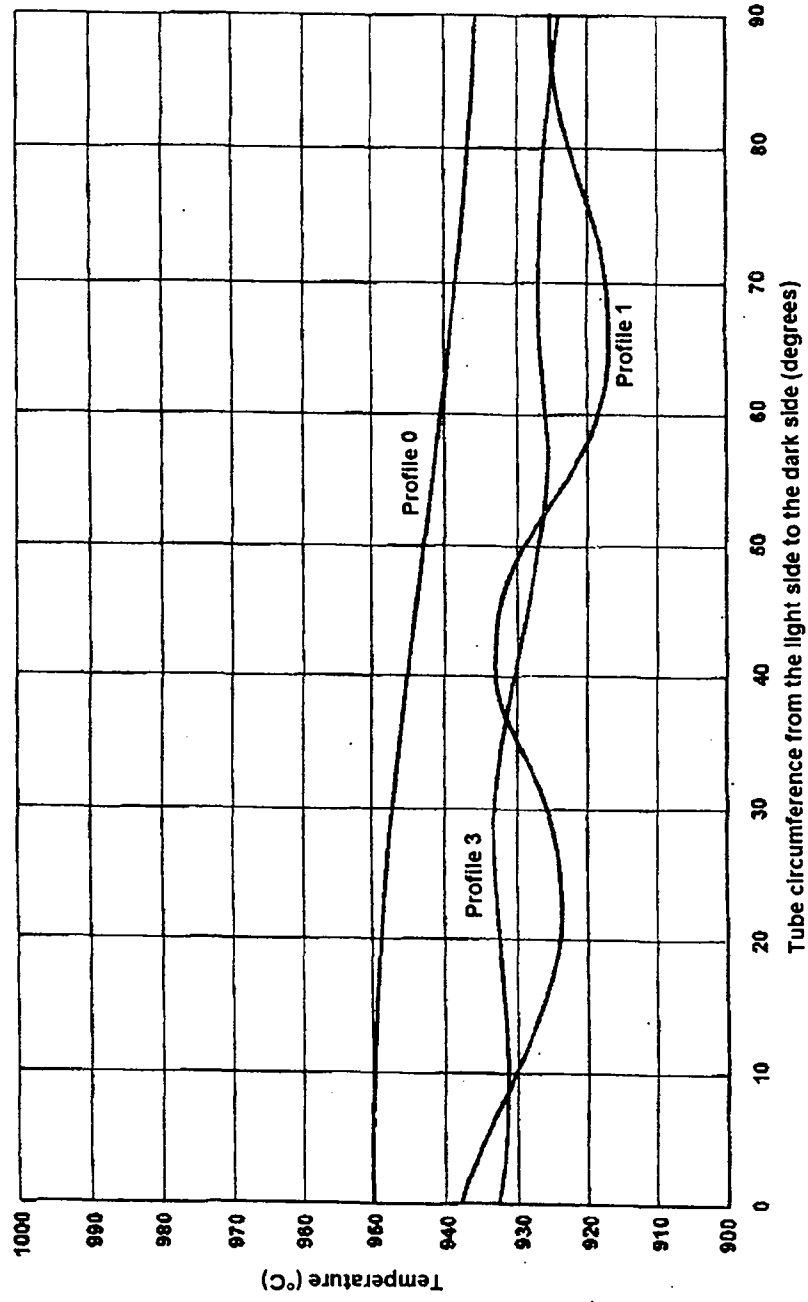


Fig. 5

Temperature distribution on the tube inner wall at 9950 mm

Superimposition of diagrams P0.5.8, P1.5.8 and P3.5.8 from
the IFS Hanover

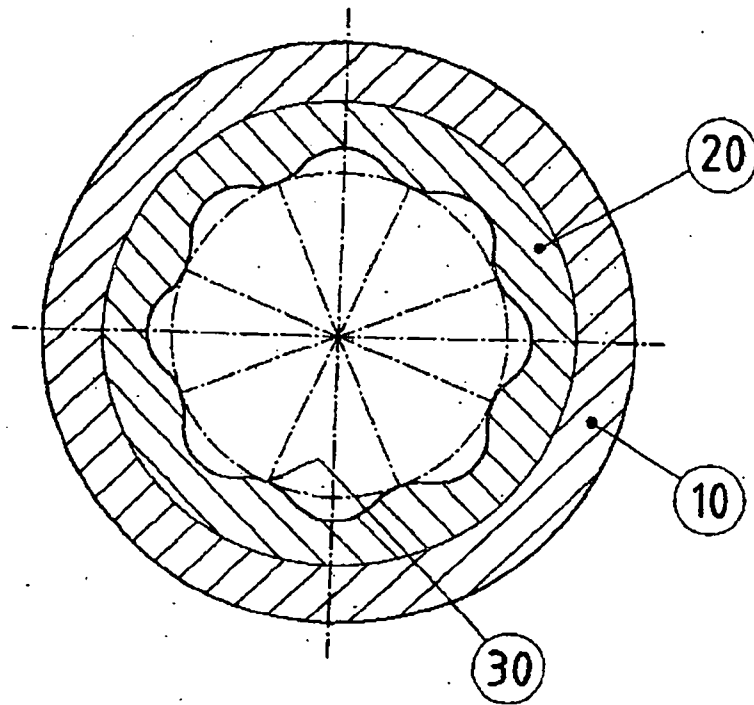


Figure 6