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(54) A tunnel kiln.

(57) A tunnel kiln, including a preheating zone, a firing zone, and a cooling zone comprises a top wall (12) and a pair of opposite side walls (13), which define a tunnel. At least at the firing zone, the top wall or roof (12) and each of the side walls (13) are formed by a pair of oppositely arranged inner and outer shells (16,17), which are mutually spaced substantially in their full extent. A plurality of burners (28) are mounted in each of the side walls (13) and the firing zone, and combustion air is supplied to each of the burners through a combustion air inlet (33), which communicates with a space (22) defined between the inner and outer shells (20,21). Because the combustion air supplied to the burners flows through the space defined between the top and side walls, a substantial part of the heat loss through the top and side walls of the kiln may be regained and used for preheating the incoming fresh combustion air without contaminating the same by combustion gases.

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A TUNNEL KILN

The present invention relates to a tunnel kiln, especially for thermal treatment of ceramics, or refractory workpieces. Such tunnel kilns comprise a tunnel including transporting means for transporting the workpieces to be treated in a longitudinal direction through the tunnel. The transporting means may, for example, be constituted by kiln cars or by a series of juxtaposed rotatable rollers extending transversely to the direction of movement of the workpieces. When the workpieces are moved through the tunnel from one end thereof to the opposite end, they are subject to successive thermal treatment steps by passing through various treatment zones of the kiln. Thus, the kiln may include a preheating and degassing zone, a firing zone, and a cooling zone. At least at the firing zone the inner walls of the tunnel is made from refractory material, and opposite sides of the tunnel a plurality of burners are arranged for providing the heat necessary for firing the workpieces. The combustion gases are preferably drawn out countercurrently to the direction of movement of the workpieces through the kiln so that the incoming fresh workpieces are preheated by the combustion gas being drawn out from the kiln.

In order to increase the "available heat" for the firing it is desirable to increase the temperature of the flames from the burners to the highest possible extent. Such flame temperature increase may be obtained by one or more of the following expedients:

1) burning the fuel at a stoichiometric ratio to avoid heating of surplus combustion air,
2) enriching the combustion air with oxygen to further decrease the necessary amount of combustion air, and
3) preheating the combustion air.

The temperature in the firing zone of the kiln may be rather high, for example about 1100°C, and therefore the loss of heat through the surrounding kiln walls is substantial even when these walls are rather thick, for example about 500 mm, and at least partly made from thermally insulating material.

Several efforts have been made to reduce the loss of heat by regaining part of the heat passing from the inner of the kiln transversely through the kiln walls. Thus, UK patent application GB 2103773A discloses a tunnel kiln having recuperators arranged in the roof or side walls of the kiln in the zone immediately downstream of the firing zone. The hollow recuperators are connected in series by frustoconical tubes and extend in the longitudinal direction of the kiln. Ambient air is moved through the recuperator and heated so that hot gases are drawn from the interior of the tunnel into the recuperator via inflow passages. The mixture of heated ambient air and combustion gases from the cooling zone of the kiln may be used as preheated furnace combustion air.

Ovens or kilns in which the combustion air supplied to the burners is preheated in various kinds of recuperators forming part of the walls of the kilns or ovens, are disclosed in for example US patent specifications Nos. 3,476,368, 4,125,354, and 4,664,618, and in British patent specification No. 815,643.

In all of these known structures the recuperators built into the walls of the ovens or kilns are rather complicated and cover only part of the kiln wall surfaces through which heat is lost.

The present invention provides a rather simple tunnel kiln of the type described above, in which a substantial part of the heat loss through the top wall or roof and side walls of the kiln may be regained and used for preheating the incoming fresh combustion air without contaminating the same by combustion gases.

Thus, the present invention provides a tunnel kiln including a preheating zone, a firing zone, and a cooling zone, said kiln comprising a top wall or roof and a pair of opposite side walls, which define a tunnel, the top wall and each of the side walls at least at the firing zone being formed by a pair of oppositely arranged inner and outer shells which are mutually spaced substantially in their full extent, a plurality of burners mounted in each of the side walls at the firing zone, each burner having inlets for fuel and combustion air, respectively, the combustion air inlet at each burner communicating with the interconnected spaces defined between said inner and outer shells of the top and side walls, and air supply means for forced supply of combustion air into said interconnected spaces.

Because the spaced inner and outer shells define therebetween a flow passage for incoming combustion air extending over substantially the total area of the top and side walls, the loss of heat through the side walls to the ambience is substantially reduced. A substantial part of the heat passing through the walls is namely taken up by the inflowing combustion air which is thereby preheated. This is obtained by a very simple structure, because each of the inner and outer shells may be formed as a separate unit, while the flow passage for combustion air is simply formed by the spacing defined between such separate units.

The air supply means for supplying fresh combustion air may be connected to the space of the top wall, and the burners may be arranged at the bottom part of each of the side walls. The inflowing cool combustion air will then first come into contact with the top wall of the kiln at a position, where the wall temperature is at a rather high level. From this entrance air will flow through the top wall and downward through the side wall to the burners. The air supply means are preferably connected to said space adjacent to a longitudinal center line of the top wall, whereby a substantially symmetrical air flow is obtained.

The inner shell of the top wall or roof and of the side walls preferably comprises ceramic fibre material or other refractory material which has the necessary mechanical strength, and which is able to withstand the high temperatures prevailing in the firing zones of the kiln. The outer shell may be of a less heat-resistant material and comprises preferably also an outer heat insulating layer. Such materials are of a certain porosity, so that hot gases from the tunnel of the kiln may to some extent pass outwardly through the kiln wall, which will give rise to an increased loss of heat. In order to prevent such flow of hot combustion gases through the top and side walls and thereby further reduce the heat loss, the outer side of the inner shell and the inner side of the outer shell are preferably covered by a layer of material which is substantially gas impervious. Such layer may be a sheet or plate of any material which is sufficiently heat resistant, such as metal. Such metal should preferably be of a type which does not give rise to any discolouration of the goods being treated or any other adverse effects. Thus, the metal sheets are preferably made from stainless steel.

The width of the space defined between the inner and outer shells of the top wall and the side wall, respectively, may vary in any desired manner along the path of air flow from the air supply means to the combustion air inlets of the burners. Furthermore, each of the top and side walls may be built up from a plurality of prefabricated double wall units, each comprising interconnected inner and outer shell parts. In the preferred embodiment, however, the top wall and the opposite side walls of the firing zone are formed by pairs of inner and outer shell members, each having an inverted, substantially U-shaped cross section, a space of substantially uniform width being defined between the outer surface of the inner shell member and the inner surface of the outer shell member.

As mentioned above, the inner shell of each of the walls may be made substantially from refractory brick material, and the outer shell of each of the walls may be made substantially from a thermally insulating material. It may be desirable to choose a relatively large wall thickness in order to reduce heat loss through the walls. On the other hand, a substantial increase of the wall thickness means a heavy increase of kiln construction costs. As a suitable compromise, the total thickness of each of the top and side walls may be chosen within the range 300-800 mm, preferably 400-600 mm.

The substantially uniform spacing of the inner and outer shells is chosen so as to obtain a suitable flow rate of the combustion air flowing therethrough. It has been found that the width of the spacing is suitably 20-50 mm, preferably about 30 mm.

The invention will now be further described with reference to the drawing, wherein

Fig. 1 is a perspective view of a module of the firing zone in an embodiment of the tunnel kiln according to the invention, certain parts having been cut away to better illustrate the structure,

Fig. 2 is a diagrammatic cross section of the tunnel kiln according to the invention, where the temperature of the combustion air flowing from a combustion air supply to the air inlet of a burner has been graphically illustrated as a function of the distance from the said air supply,

Fig. 3 graphically illustrates the temperature distribution in one of the side walls of a conventional kiln at a location just before the combustion air inlet to one of the burners

Fig. 4 graphically illustrates the same as Fig. 3, but in one of the side walls of the kiln according to the invention and shown in Fig. 1, and for two different rates of combustion air flows,

Fig. 5 graphically illustrates for two different rates of combustion air flows, the temperature distribution across the top wall or roof of the kiln shown in Fig. 1 800 mm from the combustion air supply, which means from the longitudinal symmetry plane of the kiln, and

Fig. 6 is a diagram illustrating the total heat loss all the way from the combustion air supply to the combustion air inlet of a burner, for different mass flows of combustion air in a conventional tunnel kiln which has been modified in accordance with the present invention.

Fig 1 shows a module 10 of a tunnel kiln for thermal treatment of ceramic or refractory workpieces 11. The kiln may comprise several juxtaposed modules, which in combination define a tunnel kiln having a preheating zone, a firing zone, and a cooling zone. The module 10 shown in Fig. 1 is of the type forming the firing zone.

Each module 10 is of an inverted U-shape and comprises a top wall or roof 12, and a pair of opposite side walls 13. The top wall or roof 12 is formed by inner and outer shells 16 and 17, and each of the opposite side walls 13 is formed by inner and outer shells 18 and 19. The inner shells 16 and 18 form a unitary inner shell member 20, and the outer shells 17 and 19 similarly form a unitary outer shell member 21. Each of these shell members 20 and 21 is shaped substantially as an inverted U or like a portal, and the inner and outer shell members are arranged in a mutually spaced relationship so as to define a narrow space 22 between adjacent opposite surfaces of the inner and outer shell members 20 and 21. The inner surface of the outer shell member 21 and the outer surface of the inner shell member 20 are preferably covered by a lining or plate of a gas impervious material, such as a sheet or plate of stainless steel or another suitable metal. This means that the narrow air space 22 which extends substantially along the total outer and inner surfaces of the inner and outer shell members 20 and 21, respectively, is defined between opposite metal plates or metal sheets. The narrow air space 22 may be closed at both ends of each module 10, so that the metal sheets or plates form a narrow air chamber of an inverted U-shape between the inner and outer shell members 20 and 21.

The inner shell 16 of the top wall 12 may consist of an inner layer of a high temperature ceramic fiber material and an outer layer adjacent to the space 22 of a low temperature ceramic fiber material. The inner shell 18 of the side walls 13 may be made from a ceramic fiber material sandwiched between an inner refractory slab lining and an outer ceramic slab lining. The outer shells 17 and 19 of the top wall 12 and the side walls 13, respectively, are normally made from mineral wool. If necessary, an inner layer of high temperature resistant mineral wool and an outer layer of low temperature resistant mineral wool may be used. The module 12 may also comprise an outer frame work or skeleton 23 supporting the module, and the outer surfaces of the module may be covered by a cladding 24 formed by cover plates.

As best shown in Fig. 2, the workpieces 11 to be treated, such as toilet bowls, are arranged on a ware deck 25 which by means of flame posts 14 is supported by a layer of ceramic insulation 15 arranged on the steel frame of a carriage or kiln car 26. The car 26 may be moved in a longitudinal direction through the tunnel kiln along rails 27 extending therethrough.

Each of the modules 10 forming the firing zone of the tunnel kiln, is provided with a number of burners 28, for example four burners in each of the opposite side walls 13. Gaseous fuel is supplied to the burners through a gas supply tube 29 and gas feeding tubes 30 branched therefrom. Combustion air is delivered to the burners through a combustion air supply tube 31, which is communicating with the narrow air space 22 through an air manifold tube 32. The manifold tube 32 is preferably connected to the air space 22 along the center line of the top wall 12 between each pair of oppositely arranged burners 28. The space 22 defined between the inner and outer shell members 20 and 21 communicate with a combustion air inlet 33 for each of the burners 28. The supply of combustion air to the burners is controlled by means of a control device 34 in dependency of the amount of fuel supplied to the burners.

In operation of the tunnel kiln the heating zone and the workpieces 11 present therein are heated to a desired high temperature, for example about 1100°C, by means of the burners 28. A controlled amount of gaseous fuel is currently supplied to each of the burners 28 through the gas feeding tubes 30, and corresponding amounts of combustion air from the ambient atmosphere are supplied through the manifold tube 32 under the control of the control device 34. Fresh combustion air supplied through the manifold tubes 32 flows in opposite directions through the narrow space 22 in the top wall 12 through the space defined in the opposite side walls 13 and into the combustion air inlets of the oppositely arranged burners 28. The combustion gas flowing from the manifold tube 32 through the narrow space 22 to the burners 28 will be preheated by heat having passed from the inner tunnel of the kiln and through the inner shell member 20. Thus, heat which would otherwise have been wasted is returned to the heating zone of the tunnel, and the preheating of the combustion air causes that a higher temperature may be obtained within the tunnel as will be described more in detail in the following.

Fig. 2 illustrates the preheating of the combustion air flowing from the manifold tube 32 through the narrow space 22 to the burners 28. As illustrated in Fig. 2, the temperature T(x) of the combustion air will increase from ambient temperature at the inlet of the manifold tube 32 to the air inlet 33 of the burners 28. It is understood that the combustion air flowing through the space 22 in the top wall 12 has a substantially lower temperature than the preheated air flowing downward through the space 22 of the side wall 13. This means that the combustion air will cool the top wall to a higher extent than the side walls.

Fig. 3 and 4 graphically illustrate the temperature distribution in a side wall of a tunnel kiln at a location just before the combustion air inlet to one of the burners 28. Fig. 3 shows a conventional kiln side wall formed by various layers, namely an inner layer of refractory slabs RS with a thickness of 50 mm, a succeeding layer of the ceramic fibers CF with a thickness of 220 mm, a layer of ceramic slabs CS with a thickness of 30 mm, a layer of high temperature resistant mineral wool HT MW with a thickness of 120 mm, and an outer layer of low temperature resistant mineral wool LT MW with a thickness of 80 mm. Thus, the total wall thickness

is 500 mm. Fig. 3 illustrates the temperature distribution when the inner kiln temperature is 1100 °C, and the ambient temperature is 30 °C. Under these conditions the loss of heat energy through such a conventional kiln wall will be
Q = 280 kcal/m^2 per hour.

Fig. 4 illustrates the temperature distribution in a kiln wall which has been modified in accordance with the present invention. This means that the walls of Figs. 3 and 4 are identical with the exception that in Fig. 4 the thickness of the layer HT MW of high temperature resistant mineral wool has been reduced by 25 mm, so as to provide an air space 22 between the adjacent layers CS and HT MW. The inner kiln temperature and the ambient temperature are the same as in Fig. 3. However, a flow of combustion air is passed to the burners 28 through the air space 22. The temperature distribution through the kiln wall is illustrated for two different flow rates of the combustion air through the space 22, namely corresponding to a supply of 15 kg air per hour to each burner and 25 kg air per hour to each burner, respectively.

In this case the calculated heat loss through the kiln wall will be Q = 146 kcal/m^2 per hour, when 15 kg of air are supplied to each burner per hour, and
Q 96 kcal/m^2 per hour, when 25 kg of combustion air are supplied to each burner per hour.

In both cases the heat loss through the walls is dramatically lower than when a conventional wall structure as illustrated in Fig. 3 is used.

Fig. 5 shows the various layers of a typical top wall or roof of a tunnel kiln in accordance with the present invention. Such top wall has an inner layer of high temperature ceramic fibers HT CF with a thickness of 64 mm, an adjacent intermediate layer of low temperature ceramic fibers LT CF with a thickness of 25 mm, and an outer layer of mineral wool MW with a thickness of 150 mm. An air space 22 having a width of 25 mm for conducting the supply of combustion air to the burners is defined between the intermediate layer LT CF and the outer layer MW. Fig. 5 illustrates the temperature distribution through such a top wall structure for two different flow rates of combustion air through the space 22, namely corresponding to an air supply of 15 kg combustion air to each burner per hour and 25 kg combustion air to each burner per hour, respectively. Even though the total thickness of the top wall is only 264 mm, the heat loss through the wall is relatively low, because the combustion air flowing through the space 22 has a relatively low temperature. Thus, the calculated heat loss
Q = 82 kcal/m^2 per hour (15 kg air/burner), and
Q = 51 kcal/m^2 per hour (25 kg air/burner).

Fig. 6 is a diagram illustrating the total heat loss all the way from the combustion air supply to the combustion air inlet of a burner 28, for various mass flows of combustion air in a conventional tunnel kiln, which has been modified in accordance with the present invention, and in which the thickness of the side walls as well as of the top wall is 500 mm. This diagram clearly shows that the average overall heat loss of a tunnel kiln can be reduced considerably by the present invention, and that the reduction of heat loss increases substantially with increase of the mass flow of combustion air through the space 22 in the kiln walls. If, for example, the inner temperature of the kiln is 1100 °C, the heat loss will be about 400 kcal per hour per m^2 of the kiln surface when the air flow in the space 22 is zero (corresponding to a conventional kiln structure), while the heat loss is reduced to about 130 kcal per hour per m^2, when the mass flow of combustion air through the space 22 is 20 kg air per hour per meter of the kiln.

EXAMPLE 1

An embodiment of the tunnel kiln according to the invention has a kiln length of 80 m, an inside width of 2.4 m, and an inside height of 1.0 m. The firing temperature in the firing zone of the kiln is 1250 °C.

The kiln has a capacity of 2000 workpieces a day. The workpieces -each having a weight of 18 kg are - arranged on carriages or kiln cars. Each car with the necessary accessories has a total weight of 972 kg, and may carry 18 workpieces, which means 324 kg of workpieces. Thus, the total weight of a loaded kiln car is 1296 kg. The mass flow of cars and workpieces through the kiln is 6000 kg,/h, while the mass flow of workpieces is 1500 kg/h. As a conventional kiln of the above type will use 1400-1600 kcal/kg of workpieces, the total energy consumption for such kiln is 2,100,000-2,400,000 kcal/h. In such a conventional kiln the heat loss through the walls will be about 1500 kcal/h per m of the kiln length, which means that the total wall loss will be 120,000 kcal/h, when the kiln is 80 m long. Thus, in a conventional kiln having a reasonably good insulation there is a heat loss of 300-400 kcal/h per m^2 corresponding to a wall thickness of about 900 mm) Thus, the heat losses through the walls will range between 5 and 5.7% of the total energy consumption depending on the mass flow of workpieces.

EXAMPLE 2

When a kiln as that described in example 1 is modified in accordance with the present invention, it is theoretically possible to reduce the wall thickness of the kiln to about 300 mm without increasing the loss of heat energy through the wall. However, in practice problems will arise by using the known wall materials due to the high temperatures. If, however, a wall thickness of 500-600 mm is used it is possible to use a conventional kiln wall material and to reduce not only construction costs, but also loss of heat energy compared to conventional kilns. Thus, by using a kiln wall with a total thickness of 500 mm and comprising an air space in accordance with the invention, the price of the side walls and the top wall in the high temperature zone or firing zone of the kiln is reduced to about half the price of a conventional wall design, and, additionally, the loss of heat energy from the kiln will be reduced to about 20% of the heat loss in a conventional tunnel kiln. This means, that in the kiln according to the invention the loss of heat energy through the walls amounts to only 1.1% of the total heat input compared to 5.7 in a conventional kiln.

When the kiln has been modified in accordance with the invention the following results may be obtained:

The combustion air is preheated to a temperature of about 400 °C, and a flame temperature is 2250 °C. The available heat is 350:2250 = 0.61, and the total energy consumption will be 1,752,656 kcal/h, which amounts to 83% of the total energy consumption in a conventional kiln as described in example 1. Thus, by modifying the kiln in accordance with the present invention 17% of the total energy consumption may be saved.

In a conventional kiln, the kiln walls are not completely gas impervious, so that hot gases from the kiln may leak through the walls. Such ventilation loss may be rather considerable. In the kiln according to the present invention, however, the space 22 is defined between gas impervious layers, for example made from sheets or plates of stainless steel. This fact has not been taken into account in this example and will give rise to a further reduction of heat loss through the walls.

Claims

1. A tunnel kiln including a preheating zone, a firing zone, and a cooling zone, said kiln comprising

a top wall and a pair of opposite side walls, which define a tunnel, the top wall and each of the side walls at least at the firing zone being formed by a pair of oppositely arranged inner and outer shells which are mutually spaced substantially in their full extent,

a plurality of burners mounted in each of the side walls at the firing zone, each burner having inlets for fuel and combustion air, respectively, the combustion air inlet at each burner communicating with the interconnected spaces defined between said inner and outer shells of the top and side walls, and

air supply means for forced supply of combustion air into said interconnected spaces.

2. A tunnel kiln according to claim 1, wherein the air supply means are connected to the space of the top wall, the burners being arranged at a bottom part of each of the side walls.

3. A tunnel kiln according to claim 2, wherein the air supply means are connected to said space adjacent to the longitudinal center line of the top wall.

4. A tunnel kiln according to any of the claims 1-3, wherein each of said spaces is defined between opposite layers of a substantially gas impervious material forming the inner side of the outer shell and the outer side of the inner shell, respectively.

5. A tunnel kiln according to claim 4, wherein said layers are metal plates or sheets.

6. A tunnel kiln according to claim 4, wherein said metal sheets are made from stainless steel.

7. A tunnel kiln according to any of the claims 1-5, wherein the top wall and the opposite side walls at the firing zone are formed by pairs of inner and outer shell members each having an inverted, substantially U-shaped cross-section, a space of substantially uniform width being defined between the outer surface of the inner shell member and the inner surface of the outer shell member.

8. A tunnel kiln according to any of the claims 1-7, wherein the inner shell of each of the walls is made substantially from refractory brick material, while the outer shell of each of the walls is made substantially from a thermally insulating material.

9. A tunnel kiln according to any of the claims 1-8, wherein the total thickness of each of the top and side walls is 300-800 mm, preferably 500-600 mm.

10. A tunnel kiln according to any of the claims 1-9, wherein the spacing of the inner and outer shells is 20-50 mm, preferably about 30 mm.

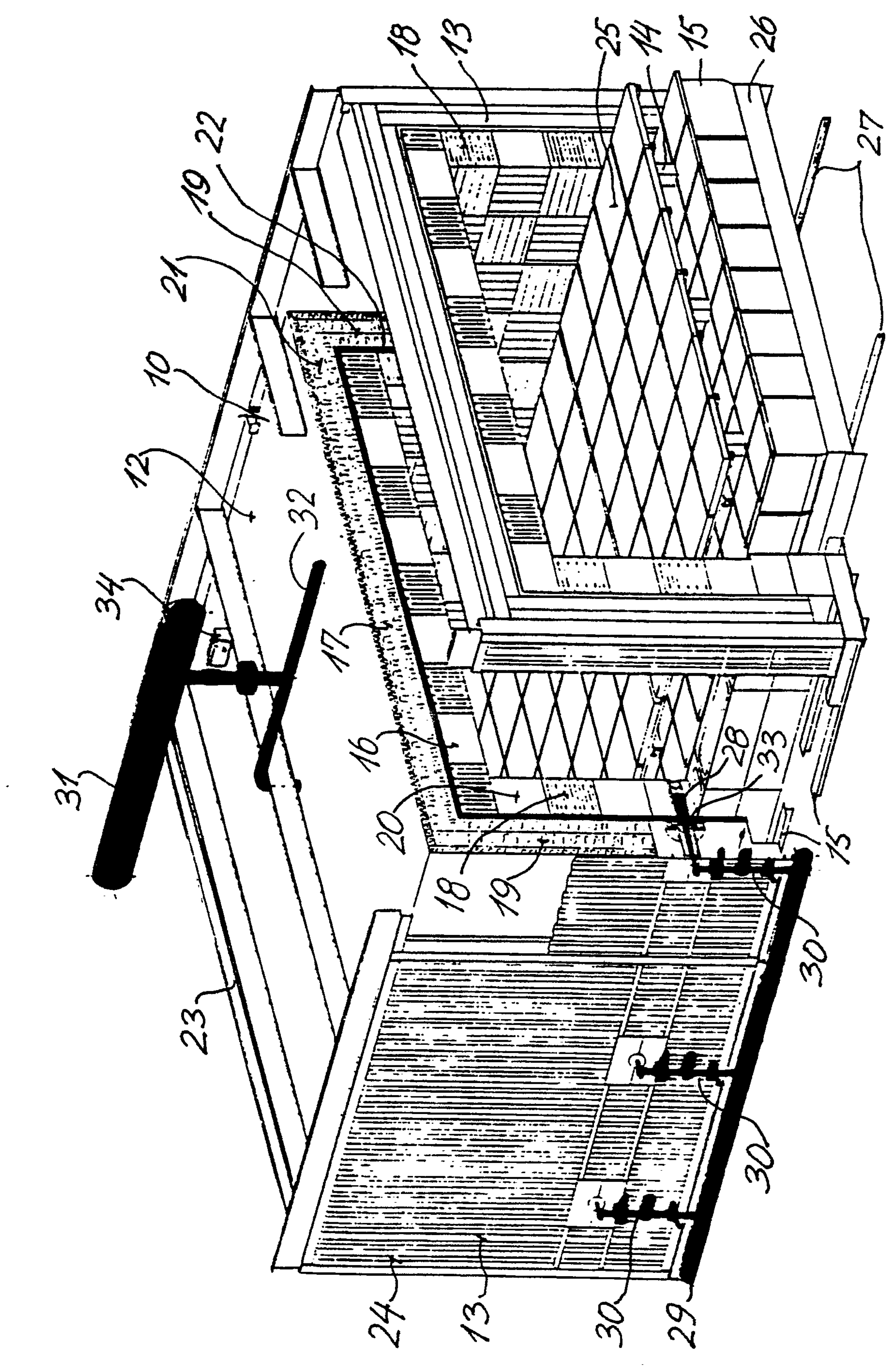

Fig. 1

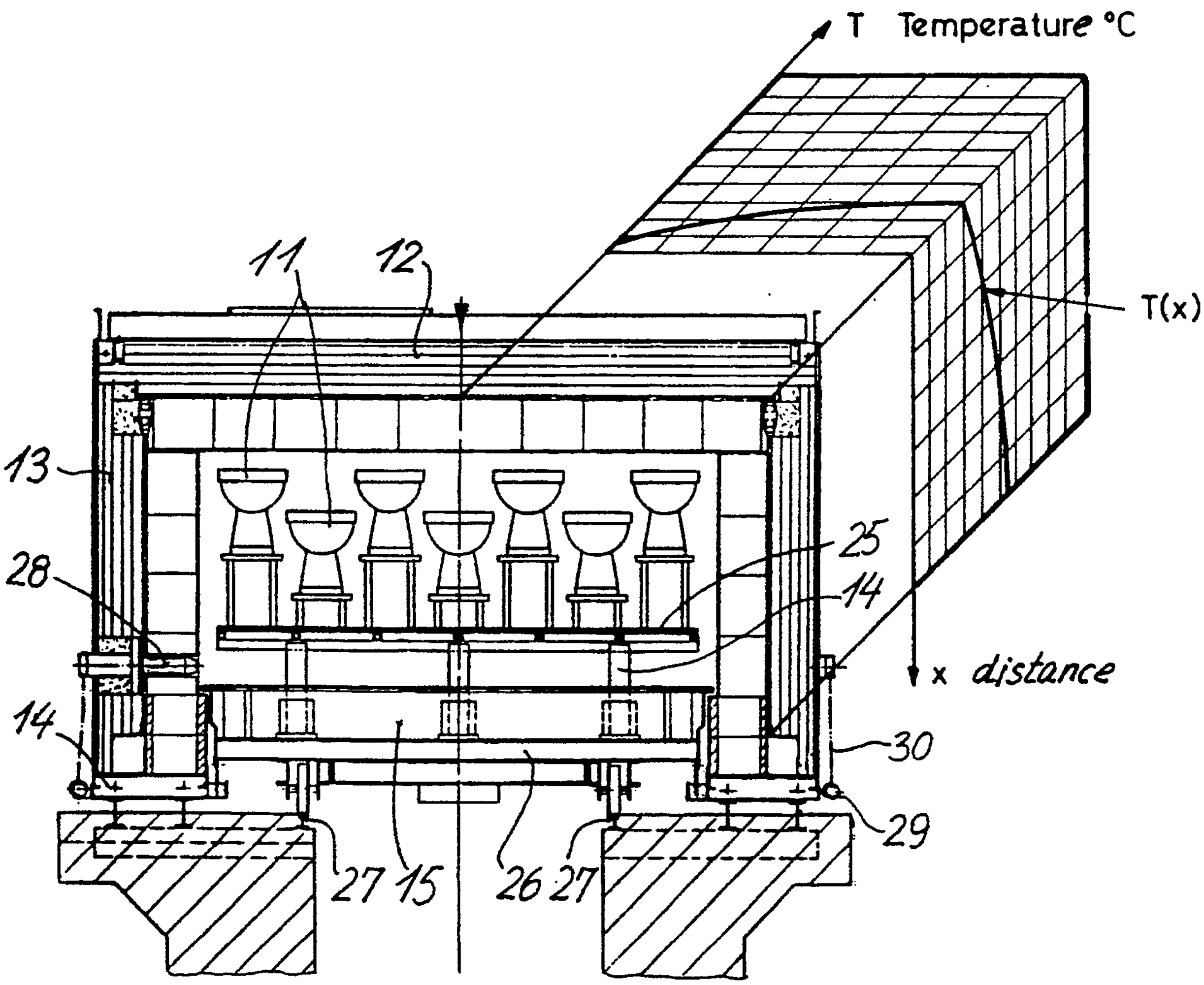
T Temperature °C
T(x)
x distance
11
12
13
28
14
25
14
30
29
27
15
26
27

Fig. 2

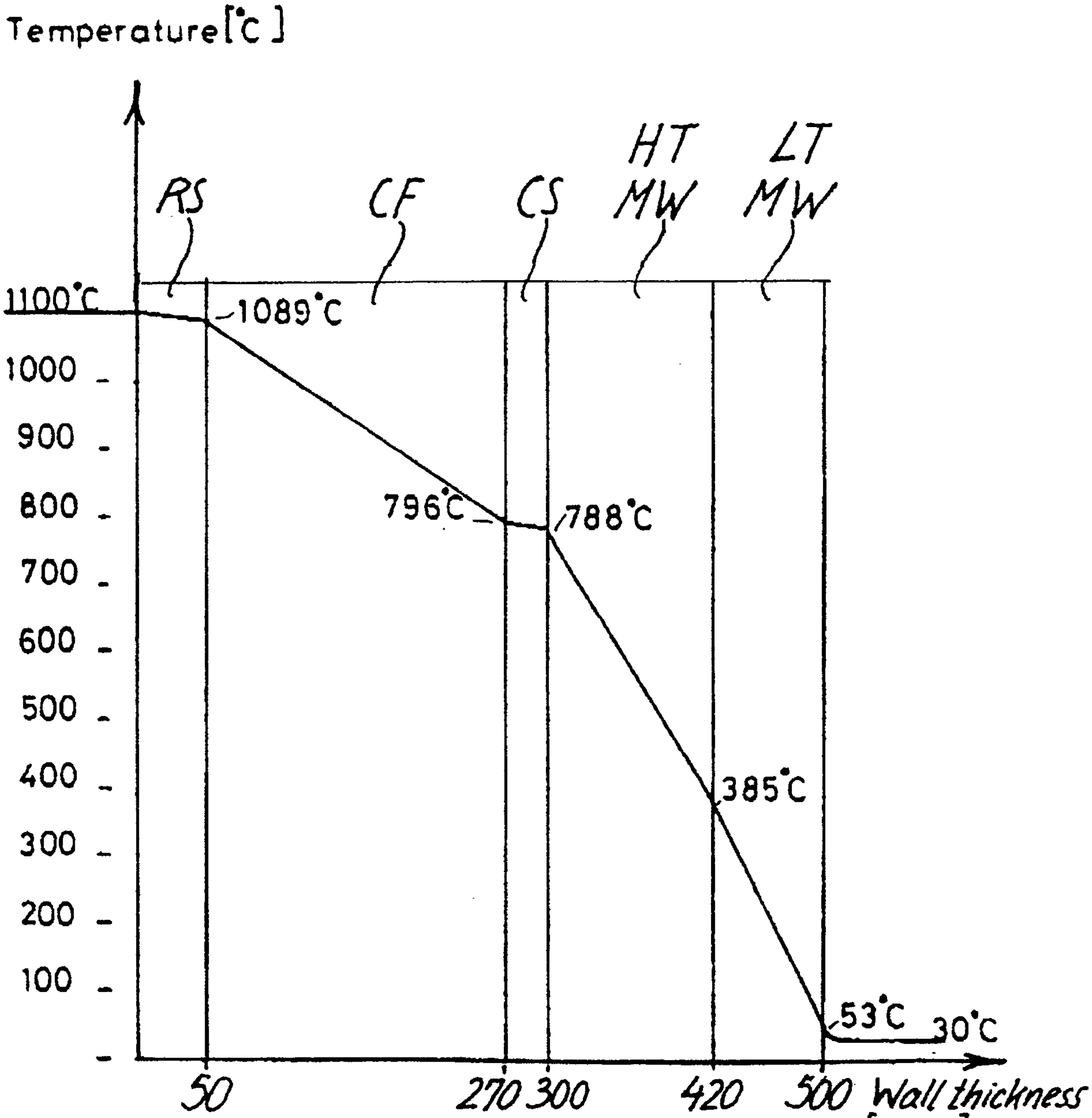
Temperature[°C]
RS
CF
CS
HT MW
LT MW
1100°C
1000
900
800
700
600
500
400
300
200
100
1089°C
796°C
788°C
385°C
53°C
30°C
50
270
300
420
500
Wall thickness [mm]

Fig. 3

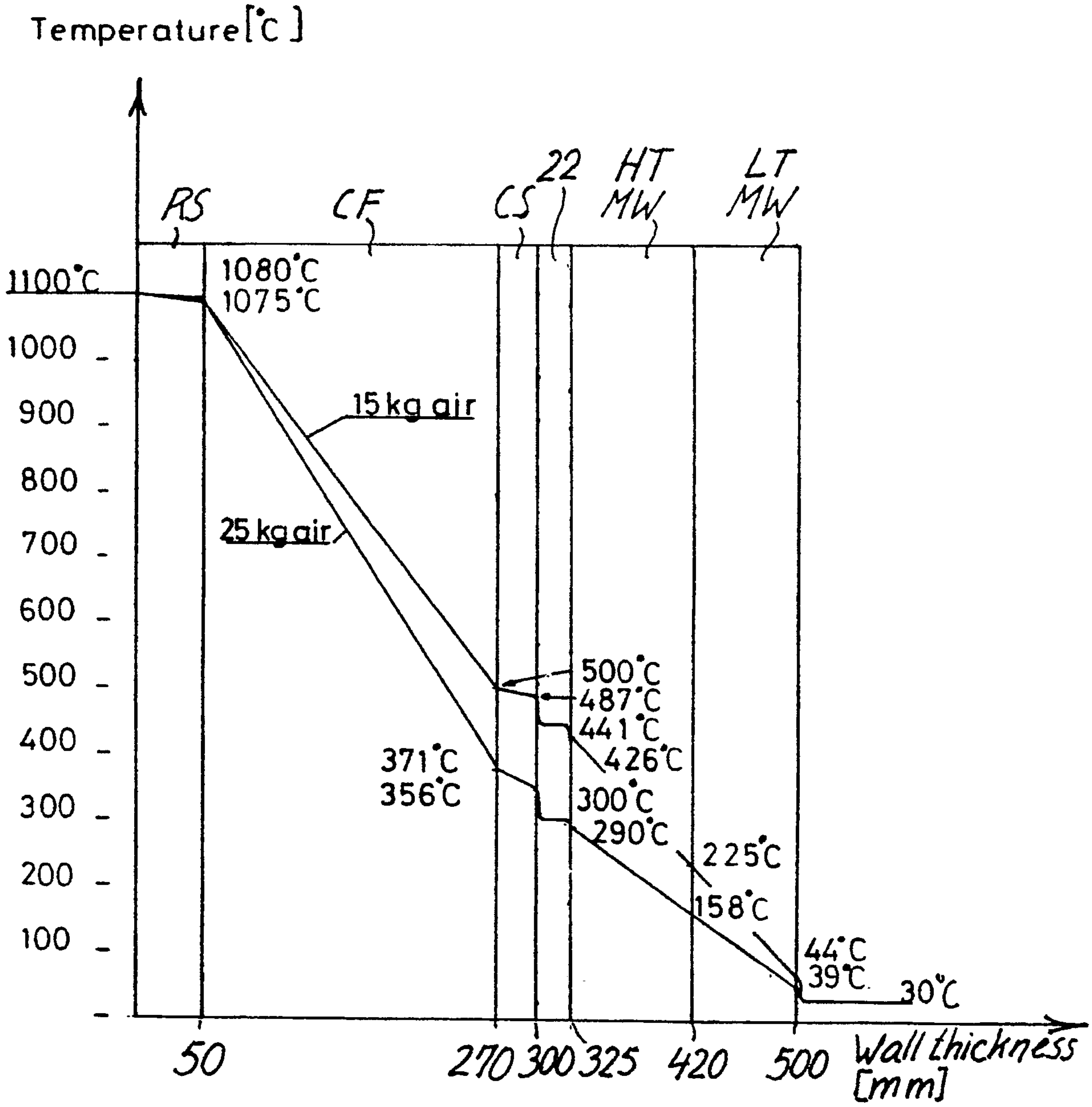
Temperature[°C]
RS
CF
CS
22
HT MW
LT MW
1100°C
1000
900
800
700
600
500
400
300
200
100
1080°C
1075°C
15 kg air
25 kg air
500°C
487°C
441°C
426°C
371°C
356°C
300°C
290°C
225°C
158°C
44°C
39°C
30°C
50
270
300
325
420
500
Wall thickness [mm]

Fig. 4

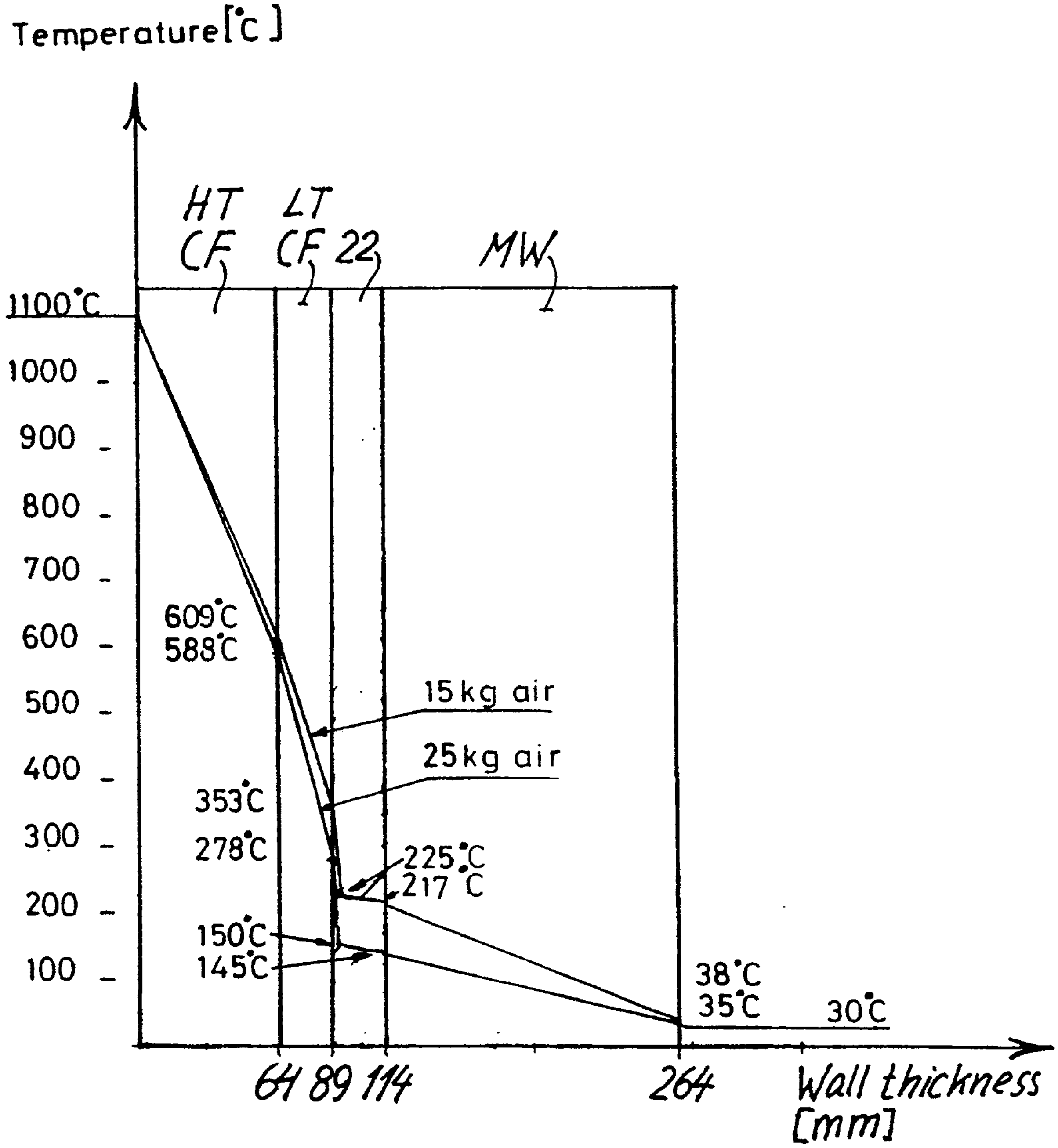
Temperature [°C]
HT CF
LT CF
22
MW
1100°C
1000
900
800
700
600
500
400
300
200
100
609°C
588°C
15kg air
25kg air
353°C
278°C
225°C
217°C
150°C
145°C
38°C
35°C
30°C
64
89
114
264
Wall thickness [mm]

Fig. 5

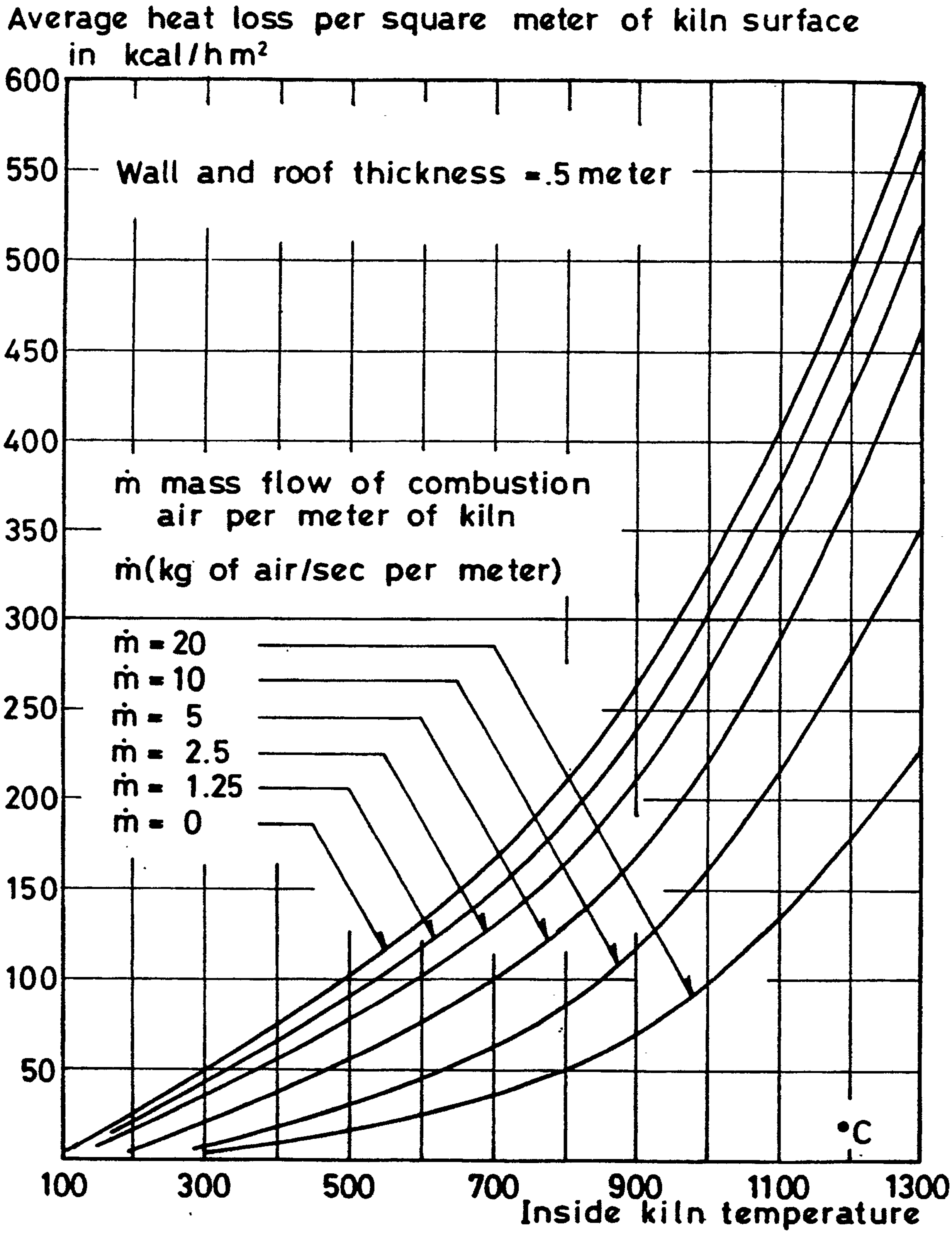
Average heat loss per square meter of kiln surface in kcal/h m²
600
550
500
450
400
350
300
250
200
150
100
50
Wall and roof thickness =.5 meter
ṁ mass flow of combustion air per meter of kiln
ṁ(kg of air/sec per meter)
ṁ = 20
ṁ = 10
ṁ = 5
ṁ = 2.5
ṁ = 1.25
ṁ = 0
°C
100
300
500
700
900
1100
1300
Inside kiln temperature

Fig. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 61 0015

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-1 510 556 (J.B. OWENS) - - -		F 27 B 9/30 F 27 D 17/00 F 27 B 9/32
A,D	WO-A-8 601 279 (AMERICAN COMBSTING) & US-A-4 664 618 - - -		
A,D	GB-A-2 103 773 (PETER STURGESS) - - - - -		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
F 27 B B 27 D

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	16 November 90	COULOMB J.C.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same catagory
A : technological background
O : non-written disclosure
P : intermediate document
T : theory or principle underlying the invention

E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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