

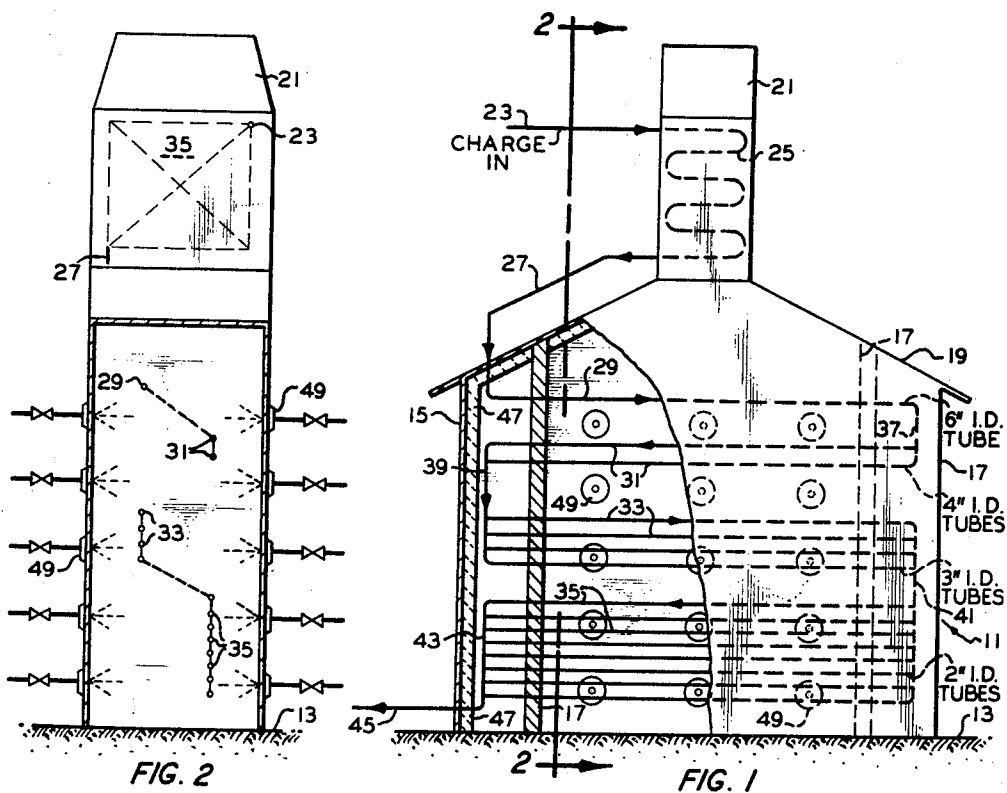
Dec. 15, 1959

L. W. POLLOCK

2,917,564

HYDROCARBON CRACKING FURNACE AND ITS OPERATION

Filed Jan. 5, 1959



INVENTOR.
L. W. POLLOCK

BY *Hudson & Young*

ATTORNEYS

1

2,917,564

HYDROCARBON CRACKING FURNACE AND ITS OPERATION**Lyle W. Pollock, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware****Application January 5, 1959, Serial No. 784,936****11 Claims. (Cl. 260—683)**

This invention relates to apparatus and method for cracking light hydrocarbons.

An object of this invention is to provide a cracking furnace and a method for its operation for cracking light hydrocarbons. Another object of this invention is to provide a furnace and a method for its operation for cracking such light hydrocarbons as propane for the production of ethylene and propylene. Another object of this invention is to provide such a method and apparatus in which the furnace tubes are constructed and operated in such a manner that they experience a relatively long and useful life. Yet another object of this invention is to provide such an apparatus and operation that a greater throughput than normal is charged to the furnace with the production of desired materials while realizing normal depth of conversion. Yet other objects and advantages will be realized upon reading the following description which, taken with the attached drawing, respectively describes and illustrates a preferred embodiment of my invention.

In the drawing, Figure 1 illustrates in a diagrammatic form a side view, partly in section, of a preferred embodiment of my invention. Figure 2 is a sectional view of my furnace taken on the line 2—2 of Figure 1.

In cracking light hydrocarbons to produce olefins in tube cracking furnaces, the limiting factor on the capacity of the furnace is usually the temperature of the metal tube. Cracked gas effluent must usually be in the neighborhood of 1500° F. to obtain high conversions of the feed. The maximum skin temperature (outside tube surface temperature) for stainless steel tubes for reasonable tube life is about 1600° F. The temperature difference between the cracked gas temperature and the tube outside wall temperature (skin temperature) is proportional to the heat flux or flow through the tube wall. By the term heat flux is meant the amount of heat, for example, B.t.u., that passes through the tube wall per square foot of outside surface of the tube per hour. Also, the heat flux for a given heat input per unit of cracked gas at constant gas velocity varies directly as the tube diameter. It is desirable to use as large a tube as possible.

In order to increase the capacity of a cracking furnace, it is proposed to use variable size tubes in the furnace. Large inside diameter tubes are used for the first part of the cracking furnace and as the skin temperature approaches the above-mentioned smaller inside diameter tubes are used in parallel. The heat flux, i.e., rate of heat transfer, for the smaller diameter tubes will be less than for larger diameter tubes and thus the tube wall temperature will be less than would be experienced on larger inside diameter tubes. For example, if a 6-inch I.D. (inside diameter) tube were used for the first part of the furnace, as the maximum skin temperature is reached for the 6-inch tube, the flow is divided between two 4-inch I.D. tubes. Again, as the 4-inch tubes approach maximum skin temperature, the flow is divided between four parallel 3-inch I.D. tubes. As the 3-inch tubes approach their maximum skin temperature, flow

2

is divided between, for example, eight parallel 2-inch I.D. tubes. Then, as maximum skin temperature is approached in these latter tubes, the material in process is withdrawn from the furnaces as product.

Referring now to the drawing, reference numeral 11 identifies a pipe heater having more or less conventional furnace walls 15, ceramic liner 47, a roof 19 and a stack 21. In the lower portion of the stack there is illustrated a preheater coil 25 for preheating of the charge stock prior to its passage into the furnace proper.

In this embodiment a first heating tube 29 is a stainless steel tube of 6-inch inside diameter (I.D.) by 36 feet long. When this tube is considered to include one return bend, the entire tube and return bend have a length of about 38.5 feet. Tubes 31 are arranged for transmission of fluid in parallel. These tubes 31 are of 4-inch I.D. and 36 feet long. Tubes 33 are 3-inch I.D. tubes 36 feet in length while tubes 35 are 2-inch I.D. and 36 feet long. Each of the tubes 31, 33 and 35, when including one return bend, is between 37.5 and 36.5 feet in length. A manifold 37 communicates one end of tube 29 with the adjacent ends of tubes 31. A manifold 39 communicates the other ends of tubes 31 with the adjacent ends of tubes 33. Another manifold 41 communicates the other ends of tubes 33 with the adjacent ends of tubes 35 while a manifold 43 communicates the outlet ends of tubes 35 with an outlet pipe 45. A ceramic lining 47 is provided throughout the interior walls of the furnace as desired. Burners 49 are positioned at such locations as desired in the side walls of this furnace. On reference to Figure 2, which is a cross sectional view of Figure 1, taken on the line 2—2, it is noted that the several banks of tubes are staggered with respect to one another. A transfer pipe 27 connects the outlet end of the preheater coil 25 with the inlet end of the 6-inch diameter heating tube 29. A pipe 23 is for inlet of charge stock to the furnace. These tubes are supported by supports 17.

In the operation of this furnace, charge stock, such as a propane stock, is introduced into the furnace through pipe 23 and passes through the preheater coil 25. The preheated stock is then transferred by way of transfer pipe 27 to the inlet end of the first and large diameter tube 29. From the opposite end of this tube the heated stock passes as divided streams through the two parallel tubes 31 which, as mentioned above, have smaller diameters than tube 29. The further heated gases from the outlet ends of tubes 31 are again divided and substantially equal volumes are passed through four parallel tubes 33 for further heating. The outlet ends of these tubes, as stated, are connected by manifold 41 and this further heated stock passes in equal streams to, for example, eight final heating tubes 35 in parallel. This finally heated stock is then collected in manifold 43 and is finally withdrawn through outlet pipe 45.

The particular operation of this furnace is as follows. In the first and large diameter tube 29 heating is such that at about the outlet end of the heating tube the outside surface of the tube reaches a temperature in the neighborhood of about 1600° F., that is, the maximum allowable skin temperature of the tube. The gas is then removed from tube 29 and the stream is divided into two portions and these are passed through at least two tubes of smaller diameters than tube 29. Since the inner cross sections of the two tubes 31 are about equal to the cross sectional area of tube 29, the velocity of the heated gases passing through tubes 31 is about the same as the velocity of the gas passing through tube 29. Thus, by the time the gas in process reaches the outlet end of tubes 31, the skin temperature of the tubes has approached a maximum allowable limit of about 1600° F. The streams from tubes 31 are combined or are passed

3

through separate manifolds, if desired, and again divided into substantially equal portions and passed through still smaller diameter tubes 33. The combined cross sectional area of the four tubes 33 is approximately the same as the combined area of tubes 31 and also the area of tube 29 so that the gases pass through tubes 33 at approximately the same velocity as they passed through tubes 31 and through tube 29. Thus, by the time the gas reaches the outlet ends of the several tubes 33, the skin temperature of the tubes has again reached approximately the maximum of about 1600° F. At this point the four streams of gas from tubes 33 are combined in manifold 41 or are, if desired, passed through separate manifolds, and are again divided into a larger number of streams as, for example, eight streams, for passing through the eight still smaller diameter tubes 35. The combined cross sectional area of these eight tubes is approximately the same as the cross sectional area of the four tubes 33, of the two tubes 31, and of the single tube 29, so that the velocity of the gases passing through tubes 35 is about the same as the velocity of the gases passing through the other tubes of the furnace. Also, by the time the gas passing through the eight tubes 35 reaches the outlet end of the tubes, the skin temperature of these tubes has again reached the maximum allowable limit of about 1600° F., and by this time conversion of the gases is sufficient and the gases are collected in manifold 43 and withdrawn from the furnace through the outlet pipe 45.

Prior art heating furnaces for such cracking operations involve the use of, for example, either a single bank or multiple banks of, for example, 6-inch inside diameter tubes. These 6-inch inside diameter tubes are arranged for serial heating of the gases undergoing conversion. If four or more of the 6-inch diameter tubes were installed in a furnace, they would be connected in series. I find that I can employ a first tube of the 6-inch variety while in place of the second 6-inch tube I substitute two smaller diameter tubes in parallel, for example, two 4-inch I.D. tubes. For the third 6-inch tube I substitute four 3-inch I.D. tubes in parallel and for the fourth 6-inch I.D. tube I substitute eight 2-inch I.D. tubes in parallel. By replacing the prior art tubes by successively smaller diameter tubes, I am able to increase the degree of conversion on passing a given charge stock through the furnace; or, if desired, I can heat to a given degree of conversion a larger amount of charge stock than in the above-mentioned prior art operation. Furthermore, by adjusting the operation I can increase the degree of conversion on a single pass through the furnace and, at the same time, increase the throughput or capacity of the furnace.

The following examples illustrate the utility of my furnace and its operation. In Example I are given operating data and stream compositions at tubes No. 1, No. 2, No. 3 and No. 4 in a furnace using four 6-inch I.D. tubes, as in the prior art. It is to be noted that the skin temperature of the outside surface of the heating tubes at their outlet ends is held at approximately 1600° F. (between 1589° to 1605° F.). In the last horizontal line of the tabulation of Example I it is noted that the percent conversion of propane to ethylene and propylene is given. This percent conversion is obtained by dividing the mols of propane per mole of feed remaining in the stream by the mols of propane per mole of feed in the original charge stock, subtracting from 1.00, and multiplying by 100. In this example the charge stock consisted of 58 mol percent propane and 42 mol percent water as steam. It is further noted that the percent conversion at the outlet of the fourth and final 6-inch diameter tube was 40.2 percent.

EXAMPLE I.—FOUR 6-INCH I.D. TUBES

Feed 11,400 lbs. propane and 3,370 lbs. steam per hour=58 mol percent propane per 42 mol percent water as steam.

4

Tube outer surface (skin) temperature about 1600° F. Four tubes, 6-inch I.D. by 36 feet long (38.5 feet includes return bend).

50 p.s.i.a.

5 40.2 percent conversion of propane—total feed 14,770 lbs. per hour.

Composition of tube effluent (mols/100 mols original feed)

	Tube No. 1	Tube No. 2	Tube No. 3	Tube No. 4
Skin Temperature.....° F.	1,604	1,598	1,589	1,605
Outlet Gas Temperature.....° F.	1,377	1,395	1,415	1,430
Heat Flux—B.t.u./hr./sq.ft.	22,676	20,655	18,319	18,351
Component:				
H ₂	2.57	4.83	6.65	8.52
C.....	0.00	0.00	0.00	.01
CH ₄	3.57	7.00	10.01	13.45
C ₂ H ₂	.01	.03	.07	.11
C ₂ H ₄	3.19	6.24	8.91	11.92
C ₂ H ₆	.48	.94	1.34	1.81
C ₃ H ₆	2.78	5.11	6.56	8.51
C ₃ H ₈	51.39	45.32	40.21	34.68
C ₄ H ₆	.01	.03	.06	.10
C ₄ H ₈	.05	.10	.17	.24
C ₄ H ₁₀	.04	.07	.08	.08
C ₅ H ₈	0.00	0.00	0.00	.01
H ₂ O.....	42	42	42	42
C ₂ H ₅	0.02	.05	.09	.15
C ₂ H ₁₀	0.01	.04	.08	.13
Total.....	108.12	111.76	116.53	121.72
Percent Conversion.....	11.4	21.9	30.7	40.2

In Example II, the feed stock to the heater was the same as in Example I, but in place of the four 6-inch I.D. tubes I use as tube No. 1 a single 6-inch I.D. tube, as tubes No. 2, I use two 4-inch I.D. tubes, as tubes No. 3, I use four 3-inch I.D. tubes and as tubes No. 4, I use eight 2-inch I.D. tubes. In this example the throughput or amount of feed stock charged to the furnace is the same as in Example I. It is to be noted that the percentage conversion was increased to 57.5 percent.

EXAMPLE II.—TUBES OF UNLIKE I.D.'s

Feed 11,400 lbs. propane and 3,370 lbs. steam per hour=58 mol percent propane per 42 mol percent water as steam.

Tube outer surface (skin) temperature about 1600° F. All tubes 36 feet long; plus return bend.

57.5 percent conversion of propane—same throughput as Example I (14,770/lbs./hr.).

Composition of tube effluent (mols/100 mols original feed)

	Tube Unit No. 1	Tube Unit No. 2	Tube Unit No. 3	Tube Unit No. 4
No. of Tubes.....	1	2	4	8
I.D. of Tubes, in.....	6	4	3	2
Skin Temperature.....° F.	1,604	1,587	1,588	1,589
Outlet Gas Temperature.....° F.	1,377	1,430	1,470	1,520
Heat Flux—B.t.u./hr./sq. ft.	22,676	21,920	16,076	13,598
Component:				
H ₂	2.57	5.06	8.21	11.41
C.....	0.00	0.00	0.00	.02
CH ₄	3.57	7.45	13.17	20.36
C ₂ H ₂	.01	.04	.10	.21
C ₂ H ₄	3.19	6.64	11.70	17.92
C ₂ H ₆	.48	.99	1.73	2.63
C ₃ H ₆	2.78	5.35	8.30	10.82
C ₃ H ₈	51.39	44.60	35.29	24.69
C ₄ H ₆	.01	.03	.09	.20
C ₄ H ₈	.05	.11	.22	.32
C ₄ H ₁₀	.04	.07	.08	.07
C ₅ H ₈	0.00	0.00	0.01	.05
H ₂ O.....	42	42	42	42
C ₂ H ₅	.02	.05	.14	.28
C ₂ H ₁₀	.01	.04	.12	.25
Total.....	106.12	112.43	121.16	131.23
Percent Conversion.....	11.4	23.1	39.2	57.5

In Example III are given data for cracking the same charge stock as in Examples I and II, but the feed rate

was considerably higher than in the two preceding examples. The feed rate in this third example was 23,632 pounds of combined feed per hour in contrast to 14,770 pounds of combined feed in Examples I and II. This third example is obtained from such an operation as produced a degree or percentage of conversion of 40.2 percent, that is, the same as in Example I. Thus, it will be understood by those skilled in the art, when the feed rate is decreased to a value less than 23,632 pounds combined feed per hour, the percent conversion is increased above the 40.2 percent of Example III. Thus, in operation, one would decide on a feed rate between 14,770 pounds per hour and 23,632 pounds per hour to give a desired percentage of conversion between 57.5% and 40.2%.

EXAMPLE III.—TUBES OF UNLIKE I.D. WITH GREATER THROUGHPUT

Feed 18,300 lbs. propane and 5,332 pounds steam per hour=58 mol percent propane per 42 mol percent water as steam.

Tube outer surface (skin) temperature about 1600° F. All tubes 36 feet long; plus return bend.

40.2% conversion of propane with total feed 23,632 pounds per hour.

Composition of tube effluent (mols/100 mols original feed)

	Tube Unit No. 1	Tube Unit No. 2	Tube Unit No. 3	Tube Unit No. 4
No. of Tubes.....	1	2	4	8
Tube Size, I.D., in.....	6	4	3	2
Skin Temperature of Tubes.....° F.	1,591	1,595	1,587	1,584
Outlet Gas Temperature.....° F.	1,381	1,435	1,478	1,529
Heat Flux—B.t.u./hr./sq. ft.	28,775	30,357	20,899	16,115
Component:				
H ₂	1.82	3.76	6.12	8.26
O.....	0.00	0.00	0.00	0.00
CH ₄	2.51	5.48	9.51	13.71
C ₂ H ₂	0.01	0.02	0.05	0.10
C ₂ H ₄	2.23	4.88	8.48	12.22
C ₂ H ₆	0.33	0.72	1.23	1.75
C ₃ H ₆	2.01	4.08	6.42	8.40
C ₃ H ₈	53.33	48.06	41.31	34.68
C ₄ H ₆	0.00	0.02	0.05	0.09
C ₄ H ₈	0.02	0.06	0.14	0.21
C ₄ H ₁₀	0.03	0.06	0.07	0.07
C ₅ H ₆	0.00	0.00	0.00	0.01
H ₂ O.....	42	42	42	42
C ₂ H ₅	0.01	0.03	0.07	0.14
C ₆ H ₁₀	0.01	0.02	0.06	0.12
Total.....	104.31	109.19	115.51	121.76
Percent Conversion.....	8.1	17.1	28.8	40.2

It is realized by those skilled in the art that the specific inside diameters and the number of the several tubes used in each of the banks of tube coils, as described hereinabove, may be varied and altered for any given problem at hand. For example, tubes 31 can, if desired, be three tubes or even four tubes, but when the larger number of tubes is used, they are, of course, of smaller inside diameter than the two 4-inch tubes 31 illustrated. Likewise, when a larger number of tubes are used as tubes 33 and as tubes 35, they are, of course, of smaller diameter than those illustrated herein.

Furthermore, if desired, more than one series of tubes, as tubes 29, 31, 33 and 35, as illustrated herein, can be arranged in a single furnace.

The example, as given herein, uses conventional stainless steel tubes, such as Schedule 40 tubes, for the cracking operation. It is realized by those skilled in the art that other hydrocarbons than propane are cracked in furnaces provided with heating tubes of other metals than stainless steel. Regardless of the particular composition of the tubes, the principles set forth in this application apply. When using conventional steel for the tubes, the maximum permissible skin temperature will obviously be considerably less than about 1600° F. For example, 75

butane, pentane or other higher boiling hydrocarbons which crack at lower temperatures than the temperature for propane can possibly use furnace tubes of other and less expensive compositions. However, when ethane is cracked for the production of ethylene, as high a temperature as possible taking into consideration a reasonable tube life, is used. The use of this furnace of my invention and the herein disclosed method of operation serves to increase markedly the length of life of the furnace tubes. Furnace tubes, particularly those of alloy materials, are very expensive and any mode of operation and particular furnace construction which increases the length of tube life is very worth-while. The term schedule as applied to furnace tubes indicates, in general, maximum allowable working pressure of a tube.

The herein-disclosed specific tube sizes are given merely as examples of the principles upon which my invention is based. It is realized that various alterations in furnace construction as regards tube size, positioning, and the like, and method of operation, may be practiced and yet remain within the intended spirit and scope of my invention.

While certain embodiments of the invention have been described for illustrative purposes, the invention obviously is not limited thereto.

I claim:

1. A furnace comprising, in combination, a combustion chamber having enclosing walls, a fuel burner operatively positioned in one of said walls, an exit for combustion gases from said combustion chamber, a plurality of radiant heating tubes disposed operatively in said combustion chamber, an inlet communicating with one end of a first heating tube of said plurality of tubes, a first manifold communicating the other end of said first heating tube with adjacent ends of a pair of second heating tubes of said plurality of tubes, said second tubes having smaller inside diameters than the inside diameter of said first heating tube, a second manifold communicating the other ends of said heating tubes with adjacent ends of third heating tubes of said plurality of heating tubes, said third heating tubes having smaller inside diameters than the inside diameters of said second heating tubes, a third manifold communicating the other ends of said third heating tubes with adjacent ends of fourth heating tubes, said fourth heating tubes having smaller inside diameters than the inside diameters of said third heating tubes, a furnace outlet, a fourth manifold communicating the other ends of said fourth heating tubes with said outlet, said third heating tubes comprising a pair and at least one additional heating tube, and said fourth heating tubes comprising at least one more heating tube than the number of third heating tubes.

2. A furnace comprising, in combination, a combustion chamber having enclosing walls, a fuel burner operatively positioned in one of said walls, an exit for combustion gases from said combustion chamber, a plurality of radiant heating tubes disposed operatively in said combustion chamber, an inlet communicating with one end of a first heating tube of said plurality of tubes, a first manifold communicating the other end of said first heating tube with adjacent ends of at least a pair of second heating tubes of said plurality of tubes, said second tubes having smaller inside diameters than the inside diameter of said first heating tube, a second manifold communicating the other ends of said second heating tubes with adjacent ends of third heating tubes of said plurality of heating tubes, said third heating tubes having smaller inside diameters than the inside diameters of said second heating tubes, a third manifold communicating the other ends of said third heating tubes with adjacent ends of fourth heating tubes, said fourth heating tubes having smaller inside diameters than the inside diameters of said third heating tubes, a furnace outlet, a fourth manifold communicating the other ends of said fourth heating tubes with said outlet, said third heating tubes comprising at

least one additional heating tube more than the number of second heating tubes, and said fourth heating tubes comprising at least one more heating tube than the number of third heating tubes.

3. The furnace of claim 1 wherein the longitudinal axes of the tubes of said plurality of tubes are mutually parallel and said fuel burner is disposed in a wall parallel to the longitudinal axes of said heating tubes.

4. The furnace of claim 1 wherein said first heating tube is positioned highest in said combustion chamber, and said second, third and fourth heating tubes being positioned successively below said first heating tube in said combustion chamber.

5. The furnace of claim 1 wherein first, second, third and fourth heating tubes of said plurality of tubes have inside diameters of 6 inches, 4 inches, 3 inches and 2 inches, respectively.

6. A method for converting in a tube heater a vaporous hydrocarbon conversion stock at a maximum conversion temperature consistent with long operating life of the heater tubes, comprising passing said vaporous hydrocarbon stock through a first heating tube, passing hydrocarbon from said first heating tube through a plurality of second heating tubes in parallel, the linear velocity of the hydrocarbon stock in said second tubes being approximately the same as the linear velocity through said first heating tube, maintaining the skin temperature of said heater tubes at approximately the maximum allowable skin temperature thereof and withdrawing converted hydrocarbon product from said second heating tubes.

7. A method for converting in a tube heater a vaporous propane stock to ethylene and propylene at a maximum conversion temperature consistent with long operating life of the heater tubes, comprising passing said vaporous propane stock through a first heating tube, passing heated propane stock from said first heating through a plurality of second heating tubes in parallel, the linear velocity of the stock in said second tubes being approximately the same as the linear velocity through said first heating tube, maintaining the skin temperature of said heater tubes at approximately the maximum allowable skin temperature thereof and withdrawing converted product comprising ethylene and propylene from said second heating tubes.

8. A method for converting in a stainless steel heating tube heater a vaporous propane stock to ethylene and propylene at a maximum conversion temperature consistent with long operating life of the heater tubes, comprising passing said vaporous propane stock through a first stainless steel heating tube, passing said propane stock from said first tube through a plurality of second stainless steel heating tubes in parallel, heating said first tube

and said plurality of tubes in such a manner that the maximum skin temperature consistent with long tube operating life is reached only near the outlet of said first tube and near the outlets of said second tubes, and removing the heated stock from said second tubes as the product of the operation.

9. The operation of claim 7 wherein said maximum skin temperature is approximately 1600° F., and the velocity of said stock passing through each second tube is approximately the same as the velocity of the stock passing through said first tube.

10. A furnace comprising, in combination, a combustion chamber having enclosing walls, a fuel burner operatively positioned in one of said walls, an exit for combustion gases from said combustion chamber, a plurality of radiant heating tubes disposed operatively in said combustion chamber, an inlet communicating with one end of a first heating tube of said plurality of tubes, a first manifold communicating the other end of said first heating tube with adjacent ends of a pair of second heating tubes of said plurality of tubes, said second tubes having smaller inside diameters than the inside diameter of said first tube in such a manner that the linear velocity of fluid in said second heating tubes is approximately the same as its linear velocity in said first heating tube, a furnace outlet, and a second manifold communicating the other ends of said second heating tubes with said outlet.

11. A furnace comprising, in combination, a combustion chamber having enclosing walls, a fuel burner operatively positioned in one of said walls, an exit for combustion gases from said combustion chamber, a plurality of radiant heating tubes disposed operatively in said combustion chamber, an inlet communicating with one end of a first heating tube of said plurality of tubes, a first manifold communicating the other end of said first heating tube with adjacent ends of a pair of second heating tubes of said plurality of tubes, said second tubes having smaller inside diameters than the inside diameter of said first tube in such a manner that the linear velocity of fluid in said second heating tubes is approximately the same as its linear velocity in said first heating tube, and outlet means for said second tubes.

References Cited in the file of this patent

UNITED STATES PATENTS

389,567	Hall	Sept. 18, 1888
477,153	Pielsticker	June 14, 1892
2,029,293	Alther	Feb. 4, 1936
2,216,471	Frame et al.	Oct. 1, 1940
2,580,002	Carrier	Dec. 25, 1951

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,917,564

December 15, 1959

Lyle W. Pollock

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 36, after "heating" insert -- tube --.

Signed and sealed this 23rd day of August 1960.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents