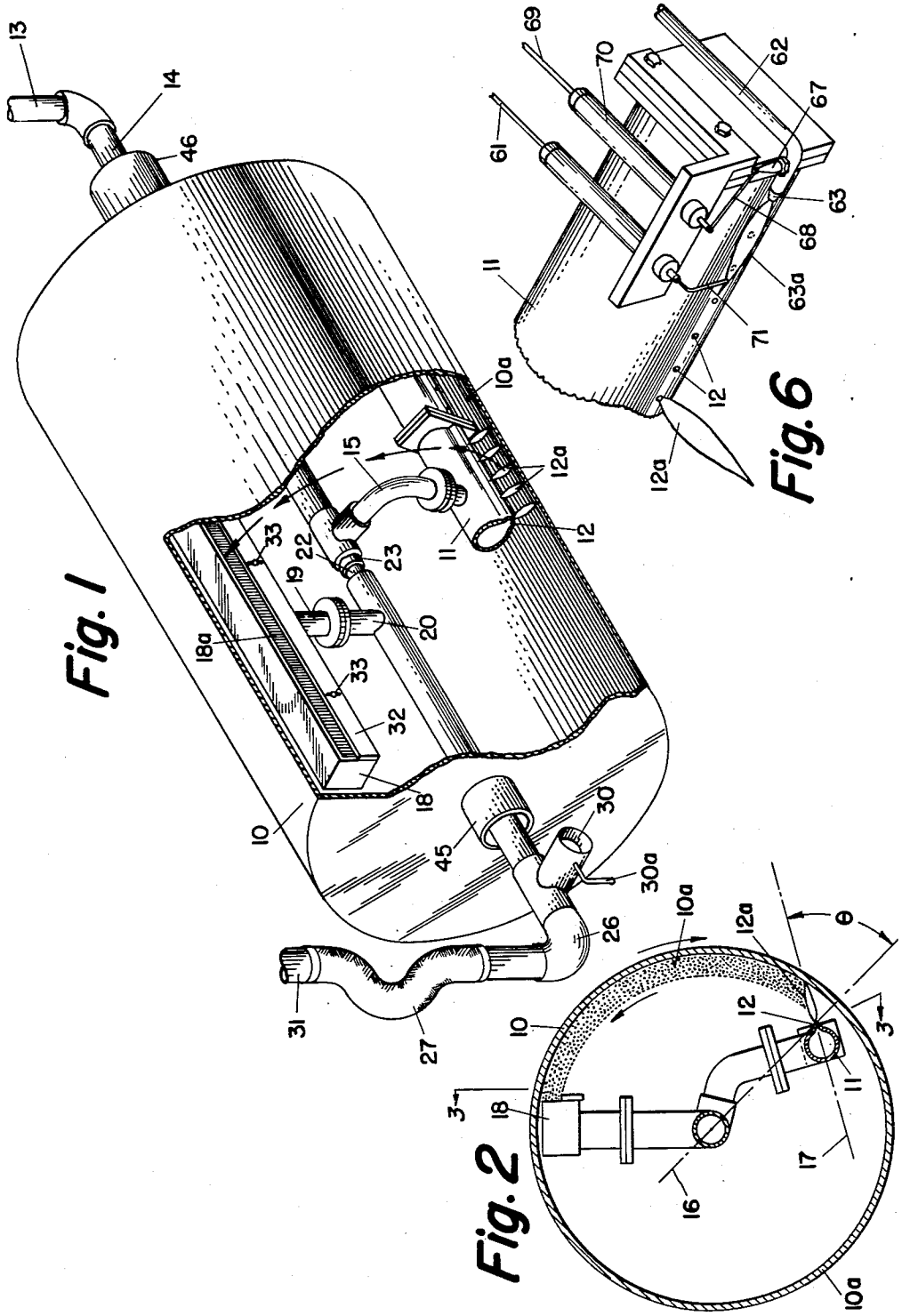
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METHODS OF AND APPARATUS FOR GENERATING AND TRANSFERRING HEAT

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METHODS OF AND APPARATUS FOR GENERATING AND TRANSFERRING HEAT

Filed May 31, 1957 4 Sheets-Sheet 2

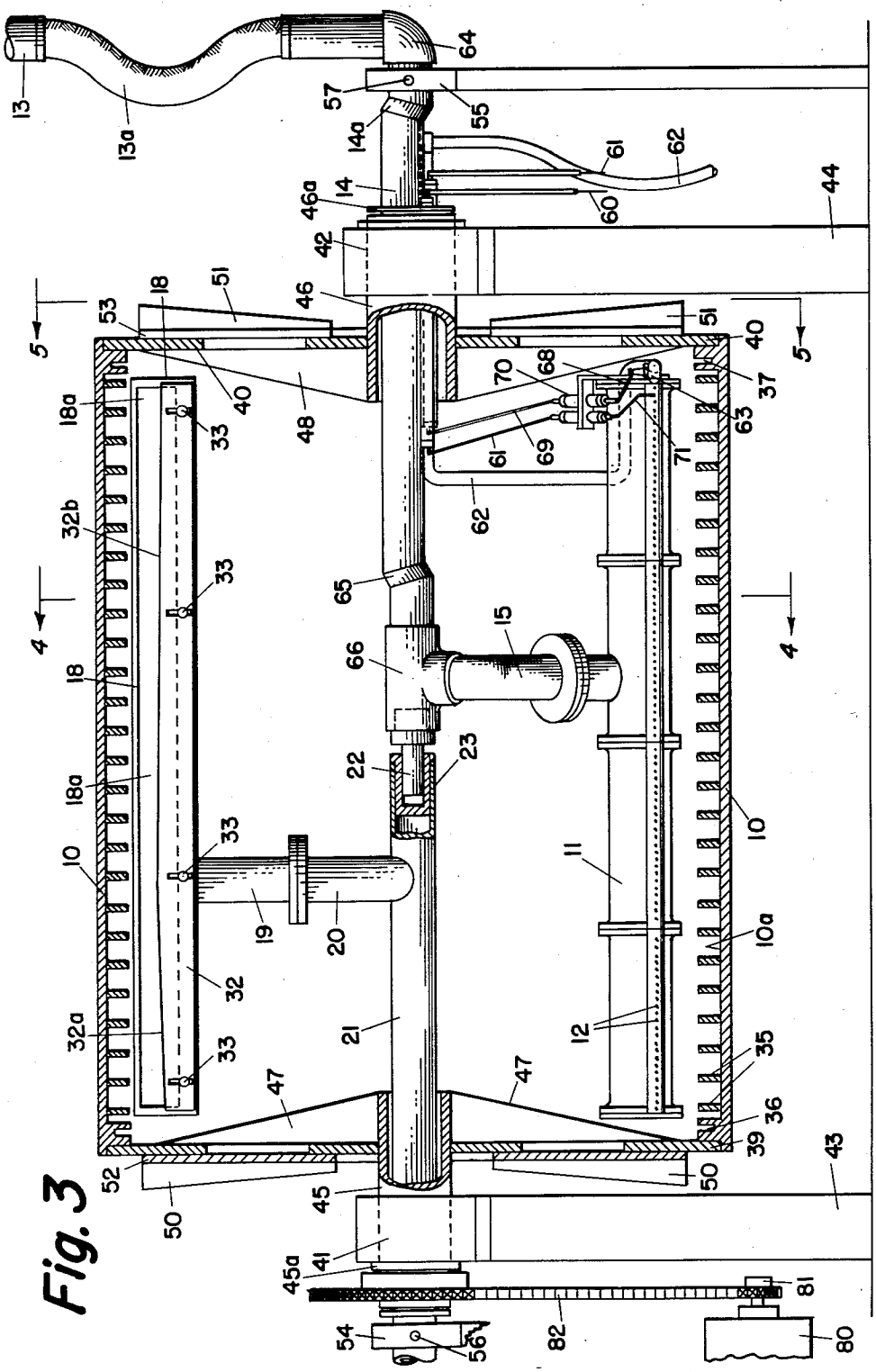


Fig. 3

Fig. 4

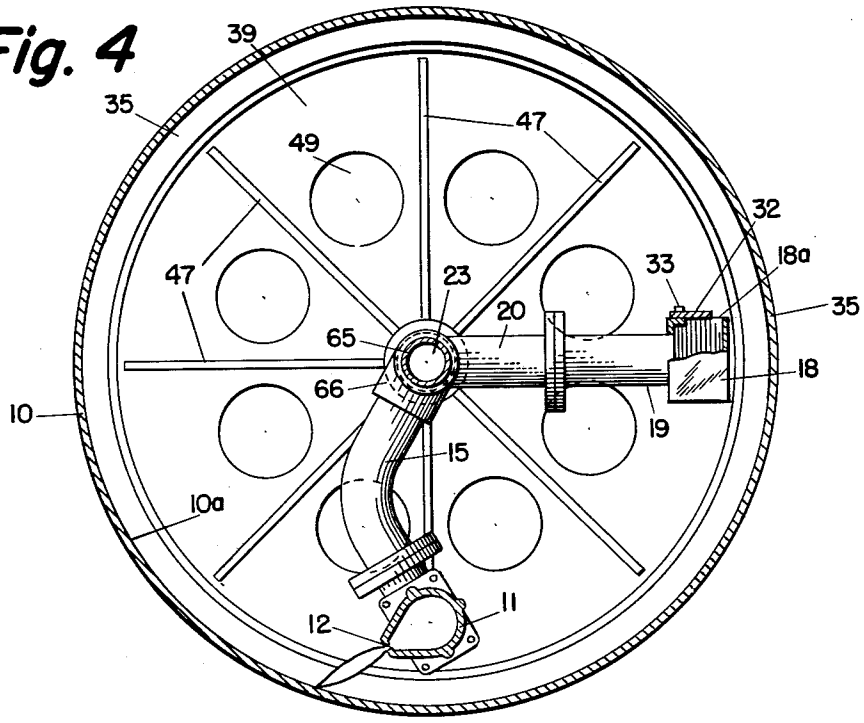
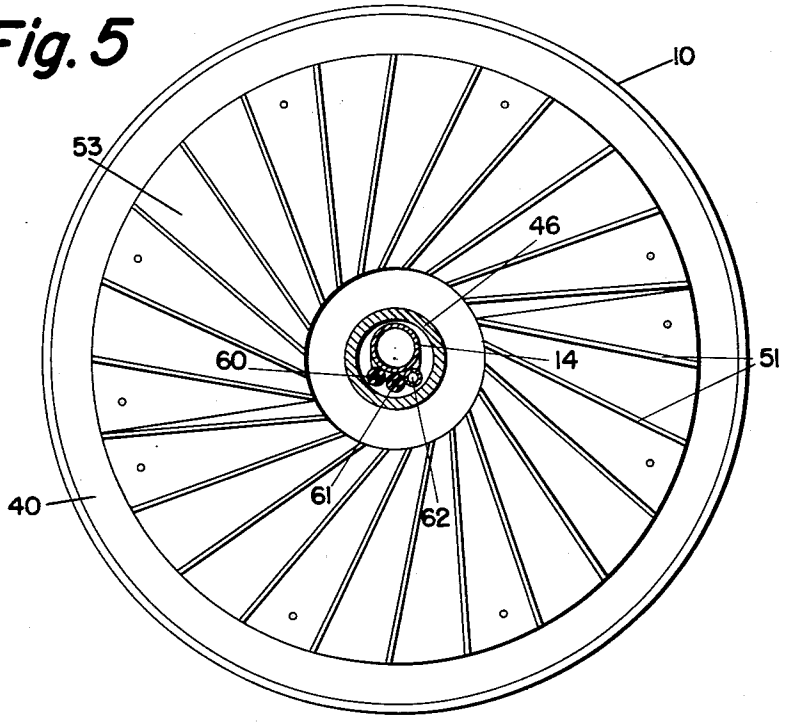

39
35
49
47
47
32
18a
33
23
35
20
65
18
66
10
19
15
10a
11
12

Fig. 5


10
53
46
60
14
51
40
61
62

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METHODS OF AND APPARATUS FOR GENERATING AND TRANSFERRING HEAT

Filed May 31, 1957 4 Sheets-Sheet 4

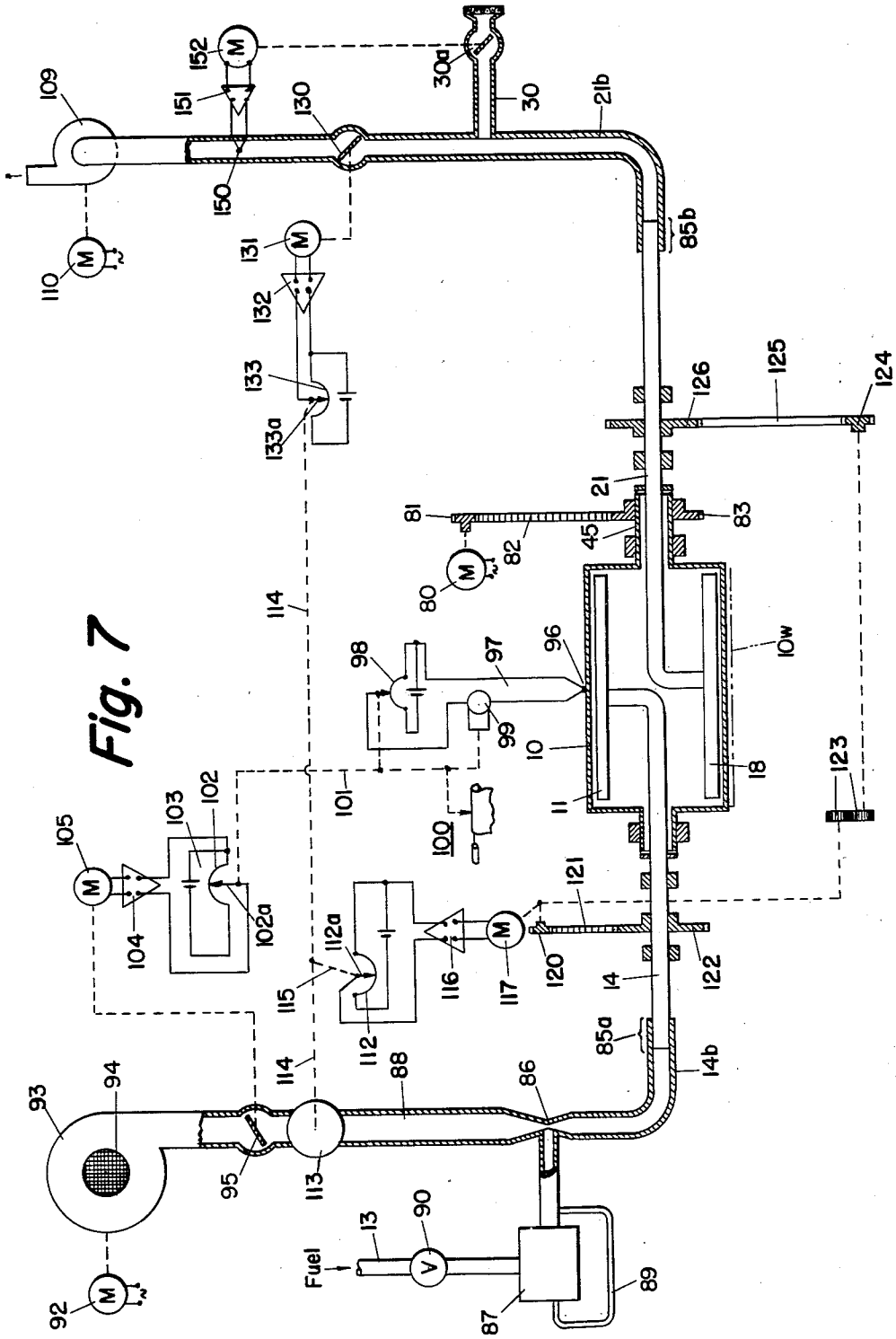


Fig. 7

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2,987,305

METHODS OF AND APPARATUS FOR GENERATING AND TRANSFERRING HEAT

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Filed May 31, 1957, Ser. No. 662,796
16 Claims. (Cl. 263—6)

This invention relates to methods of an apparatus for the internal heating of hollow cylinders.

Hollow cylinders in the form of drums, rollers and the like have for many years been used in many industries with heat applied interiorly thereof as by steam and other heating mediums. In some instances it has been proposed to place within the cylinder burners and to burn fuel within the cylinder for heat transfer to the interior surface. Where fuel has been burned within the cylinder, the heat transfer rates have been relatively low because of several factors. First, there is inherently present adjacent the inner surface of the cylinder relatively dead air which in itself forms the principal heat insulator and reduces the rate of heat transfer. The withdrawal of the spent products of combustion represents a further problem and in the past has produced eddy currents and other flow of products of combustion in directions away from the interior surface of the cylinder.

In accordance with the present invention, high rates of heat transfer to the interior surface of hollow cylinders have been attained, transfer rates as high as 30,000 B.t.u.'s per hour per square foot of said cylindrical surface. Such high rates of heat transfer have been accomplished by eliminating substantially entirely the dead air space adjacent the inner curved surface, the avoidance of any tendency of the flame and hot products of combustion to move away from the interior surface of the cylinder, and by the attainment of unexpectedly high efficiency in the convection transfer of heat from the gases to the cylinder wall.

In carrying out the invention in one form thereof, a mixture of fuel and air is directed at high velocity at an angle to the interior surface and in such angular relation that as the pre-mixed fuel is burned, there are developed tangential forces from the expanding gases and products of combustion which maintain them against the concave surface of the cylinder. The gases move along the curved surface of the cylinder in high-speed turbulent flow. By reason of the high-speed flow and the constantly changing area wiped by the gases, any dead air space is eliminated to such degree that its effect on heat transfer is inconsequential. Further to increase the attainable rates of heat transfer, the cylinder is rotated so that its inner surface moves in counterflow with the rapidly flowing products of combustion to produce turbulent flow adjacent the curved surface. Further to maintain the high-speed curved path of the hot gases, there is provided an exhaust manifold having an inlet means spaced lengthwise of the roll and under substantial negative pressure. In this manner there are withdrawn through the exhaust manifold the gases while they are disposed closely against the interior surface of the hollow cylinder.

The cylinder itself is closed at its ends, and means are provided for relative adjustment of the locations of the exhaust manifold and burner so that the angular spacing may be varied while maintaining the flow of gases in close proximity with the curved surface of the cylinder. Such spacing is varied for different rates of flow of pre-mixed fuel and also for controlling the area of the concave surface used for transfer of heat to the external load. In this manner, there may be achieved optimum conditions of operation in terms of efficiency and/or desired high rates of transfer.

For further objects and advantages of the invention, reference is to be had to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is an isometric view of an embodiment of the invention with supporting parts omitted;

FIG. 2 is a sectional view of the cylinder-heating arrangement of FIG. 1;

FIG. 3 is a sectional view, taken on the line 3—3 of FIG. 2, of a preferred modification of the cylinder-heating apparatus;

FIG. 4 is a sectional view taken on the line 4—4 of FIG. 3;

FIG. 5 is a sectional view taken on the line 5—5 of FIG. 3;

FIG. 6 is an isometric view of a fractional part of the burner and associated apparatus; and

FIG. 7 diagrammatically illustrates a complete system of control of and operation of the cylinder-heating apparatus.

Referring to FIG. 1, the invention in one form has been shown applied to a hollow cylinder **10** of the type which may be utilized for the drying of webs and sheet material of many kinds and character, the idler rollers and threading mechanism for such material having been omitted in order to simplify the drawings. Within the hollow cylinder **10** there is located a burner **11** having a plurality of openings **12** distributed lengthwise of the cylinder **10** and located in close proximity to the concave interior surface **10***a*. A mixture of fuel, preferably gas and air, under pressure, is introduced by way of supply line **13**. The pre-mixed fuel flows to the burner by way of pipes **14** and **15** into the burner manifold. After ignition, the burning pre-mixed fuel under pressure is directed angularly toward the internal surface **10***a*. The angle θ has been shown in FIG. 2 as between a radial line or plane **16** extended from the axis of the cylinder through a burner opening **12** and a line **17** coaxial of the opening **12**. Thus, it will be seen that each opening **12** directs the burning fuel in the form of a jet **12***a* angularly toward the inner surface **10***a*. By reason of the angularity of the jets relative to the surface **10***a*, the initial pressure with which the pre-mixed fuel is released through the openings **12**, and the forces developed by the expanding, burning gas, substantial tangential forces are developed tending to move the flame and products of combustion upwardly and counterclockwise of the internal surface **10***a* as viewed in FIG. 2.

It has been found that if fuel under pressure be burned in the form of a plurality of angularly directed jets in the manner described, the forces resulting from the expansion of combustion gases developed as an incident to the burning of the fuel are substantial and are effective to move the combustion gases along and in intimate convective heat transfer with the interior surface **10***a*. In accordance with the present invention, the production of and the continual expansion of gases incident to the burning of fuel are so controlled, by means of the directed jets and the constantly changing curved surface **10***a*, that there is produced along and adjacent that surface **10***a* what appears to be a confined region for the flow of the combustion gases. As will now be explained, there is produced turbulent flow of the gases and products of combustion along the surface **10***a*. The products of combustion move in wiping engagement with surface **10***a* with the elimination of the dead air blanket which would otherwise be present to reduce the attainable rates of heat transfer. By rotating the hollow cylinder **10** in a clockwise direction as viewed in FIG. 2, i.e., in counterflow with the directed streams of combustion gases, the heat transfer rate is further increased and the periphery of the drum as a whole is elevated to high temperatures for application of heat to webs and strip or sheet material of all kinds.

If the surface region **10***a* now be considered, the layer of gases adjacent that surface will be moving in a clockwise direction. These gases, as their forward velocity decreases, will exhibit a pressure change in respect to the forward moving gases. Thus, with some of the gases moving counterclockwise and some clockwise, there will be induced rotary motion or swirls which will extend along the surface **10***a* and will contribute to a high turbulent flow which is a condition desired and attained for maximum convection transfer to the cylinder wall by way of the surface **10***a*.

The length of the path of the force-directed flow of combustion gases is varied in accordance with the rate of firing of the fuel, assuming that air is always present in amount corresponding with the theoretical amount needed for complete combustion of the fuel. The provisions made for relative adjustment as between the burner **11** and a combustion withdrawing head **18** will be later described in detail.

The exhausting head or manifold **18** has suction applied to it to establish a region of low pressure in close proximity to the inner surface **10***a* and circumferentially spaced from the burner **11** for tangential withdrawal of the products of combustion while they are to some degree force-held against the internal surface **10***a*. In this manner, there is minimized any tendency of the products of combustion to move into the interior region of the cylinder **10** and thereby to create eddy currents which would interfere with the actions above described.

In addition to the forces developed by the expanding gases and the increasing velocity of the gases as a result of combustion of the fuel, there are other forces developed which contribute to the high heat transfer rates attainable in accordance with the invention. The expanding gases are, by the constraint imposed by the curved surface **10***a*, forced to move in a circular path. The result will be the development of centrifugal forces which are effective on the gases, which do have mass, to move them toward and against the surface **10***a*. Thus, there is produced a thick moving blanket of hot products of combustion along the heat-transferring area between the burner **11** and exhaust manifold **18** which presses against a layer in turbulent flow in contact with surface **10***a*. The several factors mutually contribute to the attainable high rates of heat transfer.

With fuel supplied at relatively high rate, it has been found that the exhaust manifold **18** may be located at least 180° away from the burner **11**, and with still higher rates of combustion of fuel, the self-generated forces will be effective to maintain the gases in close proximity to the concave surface **10***a* through more than 270° of its area. Typical operating data for one embodiment of the invention will be later set forth.

Further in accordance with the invention, the rate of fuel delivery from the burner **11** through the plurality of openings **12** is controlled lengthwise of the burner **11** for the production of a uniform temperature from one end of the roll to the other. More particularly, the burner openings, adjacent the respective ends of the cylinder, supply fuel at somewhat greater rates than the openings spaced from the ends. In this manner, compensation is had for certain amount of heat loss near the respective ends of the cylinder. In practice it has been found that the temperature differential, taken along a line parallel to the axis and at the outer surface of the roll in a region between the burner **11** and the exhaust manifold **18**, will be maintained constant, plus or minus 5° unloaded. With a web or other material in contact with the surface, the uniformity along the line or region of contact will be enhanced. In connection with the indicated variation in temperature lengthwise of the roll, it is to be noted that available measuring instruments are relatively inaccurate as applied to rotating surfaces, and thus it is believed that the uniformity of the temperature, notwithstanding the high rates, is considerably better than that indicated.

Contributing to the uniformity of temperature lengthwise of the roll **10** is the exhaust manifold **18**, the entrance area of the inlet means **18***a* of which is adjusted for a uniform differential of pressure lengthwise of the roll modified at the ends, however, to take care of the greater rates of flow of fuel adjacent such end portions of the cylinder. This adjustment is desirable by reason of the additional fact that the exhaust pipe **19** is connected to the manifold **18** at a point nearer the left-hand end than the right-hand end, as viewed in FIG. 1. A suction-adjusting plate **32** fastened by a series of bolts **33** is provided with slots so that the plate **32** may be inclined at an angle for a greater area at the right-hand portion of the suction opening **18***a* than at the left-hand end. In the preferred form of the invention, as illustrated in FIG. 3, it will be noted that the suction plate **32** is provided with inclined upper surfaces **32***a* and **32***b* which meet in the region of the exhaust pipe **19**, thus to provide a minimum cross-sectional area for the suction opening **18***a* in the region of the pipe **19**. The upper edge of plate **32** can be a curved surface if desired, though in practice it has been found that providing the angular shape of FIG. 3 will be satisfactory. Suction is applied to the manifold **18** by way of pipes **19**, **20** and **21**. The pipe **21** is closed at its inner end and has extending therefrom a bearing **23** in the form of a hollow cylinder which encloses a stub shaft **22** carried by the inner closed end of the fuel supply pipe **14**. This bearing **23** and external bearing means (not shown in FIG. 1) provide for the angular adjustment of the suction head **18** relative to the burner **11**.

Externally of the cylinder **10**, the pipe **21** terminates in an elbow **26**, from which there extends a flexible length of pipe **27**, such for example, as a flexible steam coupling. This flexible steam coupling is shown with a curved portion which provides needed length for rotation of pipe **21** and elbow **26** for angular adjustment of the exhaust manifold **18** relative to burner **11**. In practice, a flexible length of pipe **27** may readily provide for an angular adjustment of the manifold **18** through at least 30°, an amount adequate for most practical applications. Where a greater angular adjustment is desired, it may be facilitated as shown in FIG. 7 where pipe **21** nests within a second pipe **21***b* extending axially thereof as at **85***b* with suitable packing therebetween. With this arrangement, the manifold **18** may be moved to any angular position and without the limitation by the flexible length of pipe **27**.

To cool the exhaust gases, an air inlet **30** and valve **30***a* admit air as a cooling fluid for mixture with the gases exhausted from the cylinder **10**. The temperature requirements on the flexible pipe **27** and the subsequent disposal piping and associated equipment connected to the pipe **31** are reduced by admitting the cooling air to the exhaust gases shortly after leaving the cylinder **10**. Though not shown in FIG. 1, the branch inlet **30** includes a filter to prevent entry of any combustible matter into the hot combustion gases. In some applications the exhaust gases may be utilized as a by-product of the heating of the cylinder **10**, since they are substantially oxygen-free and, accordingly, such gases provide a relatively inert heating medium useful in many industrial processes.

The provisions for angular adjustability of the exhaust manifold **18** are also applicable to the burner **11** and to supply pipe **14**, as indicated in FIG. 7.

Now that the principles of the invention have been set forth, it is to be understood that many modifications may be made and that further and additional features can be included, all of which will mutually contribute to the objective of providing new methods and systems of generating and transferring heat by means of an internally heated cylinder or roll having exceptionally high heat transfer rates. For example, in the preferred modification illustrated in FIGS. 3–6, it will be observed that the cylinder **10** is provided with a plurality of fins **35** which are illustrated as of washer-like shape. Though they may be welded to the inner surface **10***a*, it is preferred that they

be formed by machining and thus to be integral with the wall of the cylinder. The fins **35** perform a number of functions. First, they greatly increase the heat transfer area in contact with the hot products of combustion flowing between the burner **11** and the exhaust manifold **18**. The fins **35** additionally subdivide the hot gases into a multiplicity of individual streams in the region of surface **10***a* with the overall blanket of rapidly moving gases superimposed above the subdivided streams.

While the heat transfer rates are extremely high in the regions of the surface **10***a* and of the fins **35**, annular slots **36** and **37** provide heat transfer barriers to decrease the flow of heat toward the supporting heads **39** and **40**. The slots **36** and **37** are of greater importance in the arrangement shown in FIG. 1 where there are not provided the flow-subdividing heat-transfer fins. In that modification, the hot products of combustion from the end-burner openings tend to expand along surface **10***a* and, accordingly, to transfer heat to the heads. In the modification of FIG. 3, the slots **36** and **37** may be omitted, providing the burner openings **12** terminate short of the end-most fins. Thus, the end-most fins themselves establish heat barriers relative to the heads and act to prevent flow of gases endwise of the cylinder.

Because of the high rates of heat transfer and the great release of heat within the cylinder **10**, provisions are made to minimize the temperature rise of the bearings, thereby to avoid the need of cooling fluid for such bearings. As shown in FIG. 3, the cylinder **10** is journaled in bearings **41** and **42** carried by supports **43** and **44**. The heads **39** and **40** have welded thereto cylindrical journals **45** and **46**. The journals are provided with closure members **45***a* and **46***a*. For purposes of increasing strength and rigidity of the heads **39** and **40** a plurality of gusset plates **47** and **48** are welded to the respective heads **39** and **40** and to the journals **45** and **46**. The subassemblies comprising the journals **45** and **46**, the gusset plates **47** and **48**, and the heads **39** and **40** provide the needed strength to support the cylinder **10** for rotation at any desired speed.

As best shown in FIGS. 3 and 4, openings **49** are provided between each of the gusset plates **47**. These openings, besides lightening the subassembly, provide heat-transfer barriers, that is to say, they decrease the cross-sectional area of the path from which heat can flow from the periphery of the cylinder **10** toward the journal **45** and bearing **41**.

Further to reduce the transfer of heat readily inwardly from the periphery of drum **10**, there are secured, FIGS. 3 and 5, to the outer face of the head **39** a plurality of heat flingers **50**. Similar heat flingers **51** are secured to the head **40**, FIG. 5. Each array of flngers **50** and **51** is formed integrally with backing plates **52** and **53**. As shown in FIG. 5, the heat flingers **51** are inclined with respect to radial lines and together form a fan-like structure which produces flow of a large amount of air outwardly from the journal **46**, FIG. 3, along the head **40**. By thus providing for forced cooling of the head **40**, the temperature of the journal **46** and of bearing **42**, FIG. 3, is maintained within reasonable limits and within a range for which the bearing **42** may be operated without the need of cooling fluid. In some instances, it may be desirable to provide cooling fluid for the bearings. In such event, the features just described contribute to a reduction of the amount of available cooling fluid which need be utilized, and thus such features are of advantage, either with or without cooling of the bearings.

Further contributing to the dissipation of heat is the selection of materials within the heat flow path. The heads **39** and **40** and the gusset plates **47** and **48** are preferably of a material having a low heat-transfer coefficient, such for example, as stainless steel, whereas the heat flingers **50** and **51** are of a material having a high heat-transfer coefficient, such for example, as aluminum. Thus, in the multiplicity of heat-transfer paths of high heat conductivity, there is a rapidly moving amount of cooling air to move the heat conducted thereto outwardly and away from the journals **45** and **46**. In contrast, the heat-transfer path to the journals **45** and **46** is of low heat conductivity. In this connection, it will be noted that the heat flingers **50** and **51** terminate short of the journal **46**, FIG. 5, the annular space between their inner ends providing an inlet for the flow of air between them, that annular space being in close proximity with the journal **46** and providing substantial cooling thereof.

While it may be considered that the multiplicity of gusset plates **47** and **48** within the cylinder would tend to increase the flow of heat to the journals **45** and **46** to a point which would indicate their omission, such is not the case. Aside from the required rigidity for the journal subassembly, the effective flow path for heat is sufficiently reduced and the cooling adequate for reasonably low operating temperatures for the bearings. Thus, an inspection of FIG. 4 reveals that in the region between adjacent holes **49** there is a greatly restricted cross-sectional area for flow of heat. In this region between adjacent openings, the flingers are moving a substantial amount of cooling air to transfer from that region the heat conducted thereto. Accordingly, the flingers **50** and **51** are securely fastened to the heads **39** and **40** in said regions between said openings **49** as by cap screws located within the aforesaid regions. These cap screws have not been shown in the drawings but extend through the heat flingers **51** on opposite sides of the location of the plates **47** and insure maximum rates of heat transfer from the heads to the heat flingers and the cooling air moving through them.

As indicated above, the suction manifold **18** and the burner **11** are angularly adjustable relative to each other to control the length and area of the flow path of gases against the inner surface **10***a* of cylinder **10**. For angular adjustment of burner **11**, there is included in the supply line **13**, FIG. 3, for the pre-mixed fuel and air a length **13***a* of flexible pipe-coupling, such for example, as used in steam lines. The flexible coupling **13***a* permits rotation of the pipe assembly extending to and supporting the burner **11**. As shown, the burner supply pipe **14** and the exhaust pipe **21** are provided with the bearing means **22** and **23** midway of the cylinder and also with supporting bearings **54** and **55**. Preferably, clamping means **56** and **57** in the form of set screws are provided in association with each of bearings **54** and **55** to hold in fixed angular position the burner **11** and the exhaust manifold **18**. To simplify the construction and for the use of standard parts, it will be seen from FIG. 5 that the fuel supply line **14** extends in off-center relation through the hollow journal **46**. This provides the space needed for conductors **60** and **61** and for a fuel supply line **62** which extends to a pilot burner **63**. The offset relationship of pipe **14** is provided by an offset **14***a* as between the pipe **14** and the elbow **64**. Another offset **65** in line **14** brings the T-fitting **66** to a position concentric with the cylinder and with the supporting bearings.

It is to be understood that the burner assembly and the exhaust manifold assembly may each be supported in cantilever fashion as by two external bearings, FIG. 7. If so used, the plug and socket bearings **22**, **23** may be omitted.

Returning now to the burner assembly and referring particularly to FIG. 6, it will be observed that the fuel line **62** terminates at the pilot burner **63** which projects a flame **63***a* along one or more of the openings **12** of the burner **11**. Included in the pilot burner **63** is an ignition device **67** sometimes referred to as a sparkplug. High-voltage current is supplied to the device **67** by way of conductors **60**, **69** and **68**. The conductors **60** and **69** are suitably insulated from their associated supporting structure as by ceramic spacers included in the supporting tube **70**. To initiate operation, a control circuit (not shown) is closed to produce a spark within the pilot burner **63**. This ignites the pre-mixed fuel then flowing

through line **62** to produce the flame **63***a*. It will be understood that as soon as the fuel issuing from one of the openings **12**, such as the flame **12***c*, appears, it automatically ignites in succession the streams of fuel issuing from the adjacent openings. It will be observed that the flame **63***a* from the pilot burner **63** impinges upon a flame rod **71**, which flame rod is also disposed within the flame produced by the pre-mixed fuel issuing from one of the openings **12**. The flame rod **71** is conventional. By change in its resistance due to rise in temperature, a safety circuit, including conductor **61** insulated by ceramic spacers, maintains open a fuel supply valve (such as valve **90**, FIG. 7) and closes that valve upon flame failure.

For an understanding of additional control features forming a part of this invention, reference will now be had to the operation as a whole.

Referring now to FIG. 7, it will be assumed that a motor **80** is, through a sprocket **81** and chain **82**, driving a sprocket **83** secured to the hollow journal **45** of the cylinder **10** for rotating it at a selected speed. The motor **80** may be a variable speed motor, or the speed of drum **10** may be controlled through gears or other speed-changing mechanism.

With the cylinder **10** rotating at the speed desired for a web of paper or other material undergoing drying (such web being partially wrapped around the cylinder **10** and a section of which is shown at **10***w*), the pre-mixed fuel and air will enter by way of the fuel pipe **14** as previously explained.

In FIG. 7, instead of illustrating the flexible section of pipe as shown in FIG. 3, overlapping lengths of pipe as indicated at **85***a* are to be taken as symbolic of an airtight rotatable connection between pipe **14** and the supply pipe **14***b*. The pipe **14***b* includes a Venturi tube **86**, and in conjunction with fuel mixing valve **87**, of conventional construction, adds fuel to the line **14***b* in fixed proportion to the rate of flow of air entering the Venturi as at the region **88**. The fuel control valve **87** includes a connection **89** responsive to the pressure at the low-pressure section of the Venturi tube **86**. As the flow of air through the Venturi tube increases, so does the amount of fuel supplied from the line **13**. The valve **90** is a safety shut-off valve which for the operation now being described will be considered fully open.

To simplify FIG. 7, there have been omitted the pilot burner, the flame rod, and associated auxiliary control equipment which includes numerous interlocking circuits which do not affect the operations so long as the motors and equipment are functioning normally. Upon the failure of any significant component, the system will automatically shut down.

The flow of air to the Venturi tube **86** is provided by an air blower **93** provided with a filter **94** at the air inlet. The blower is driven by a motor **92**. In the outlet line from the blower **93** a control valve **95** is utilized to vary the amount of air supplied to the burner **11**. Though the air control valve **95** may be manually set to predetermine the rate of combustion within the cylinder **10**, it has been illustrated as under the control of a thermocouple **96** responsive to the temperature of the cylinder at a selected location on its external surface. The external temperature of the cylinder varies with change in heat load imposed by web **10***w*.

The thermocouple **96** is included in a measuring circuit **97** of the potentiometer type and which includes a variable resistor or slidewire **98** and a detector **99** illustrated by the broken lines as driving a pen-index relative to a chart and associated scale of a recorder **100**. The measuring circuit and indicator-recorder **100** may be of the type illustrated in Williams Patent No. 2,113,164, dated April 5, 1938. As the temperature of the external surface of the roll **10** changes, the thermocouple **96** will respond, and the detector **99** will not only move the pen-index of the recorder **100**, but through the mechanical connection **101** will adjust the movable contact **102***a* of an input potentiometer **103** for introducing an input signal to an amplifier **104** which controls the energization of a motor **105** to adjust the position of the air control valve **95**. Thus, the position of the movable contact **102** with respect to its associated slidewire will always be representative of the temperature as measured by thermocouple **96**.

The amplifier **104** and the motor **105** are representative of control systems of the type disclosed in Davis Patent No. 2,666,170, dated January 12, 1954, the input slidewire **102** corresponding with the slidewire 31 of that patent. It is to be noted that the control system as represented by the amplifier **104** includes proportional, rate and reset actions. It will be preferred that the reset and rate actions be set at relatively low values for the reason that other adjustments can take place which may affect the positioning of the air control valve **95**. In this connection, it is to be noted that adjustment of the air control valve **95** effectively changes the fuel input to the cylinder **10**. Accordingly, it is correct to say that the control system responsive to change in the temperature of thermocouple **96** directly regulates the fuel input to the cylinder **10**. By functioning through and by means of the air control valve **95**, it is likewise assured that increased or decreased amounts of fuel will be burned within the cylinder **10** with the proper amount of combustion air for 100% combustion.

While the temperature of the external convex surface of the cylinder **10** is measured at a single point, it is to be remembered that the cylinder is rotated at relatively high speed by the motor **80**. Regardless of speed, the thermocouple **96** of the contact type measures the average temperature of the roll, which average temperature will be approximately the same throughout the circumference for any given instant. It is preferred that the thermocouple **96**, or other roll-temperature measuring device, be located within the combustion zone between the burner **11** and the exhaust manifold **18**, since any change in the rate of firing may be more quickly detected by the thermocouple. There will then be less lag in the control functions which have been partly set forth.

It will now be assumed that the heat load imposed by the web **10***w* on the heat-generating and transferring cylinder **10** is such that the air valve **95** is halfway between its maximum and minimum positions for producing a temperature as measured by the thermocouple **96** at the set point. In order to have a numerical illustration, it will be assumed that the set point as established by a control setter in amplifier **104** (such as the control point setter 42 of the aforesaid Davis patent) will be 600° F., though it is to be understood the cylinder is capable of operation at temperatures as high as 1200° F. If the temperature decreases, the valve **95** will be opened a greater amount. Since there will be an increase in fuel delivery to the cylinder **10**, it will be desirable immediately to increase the angular separation between the burner **11** and the exhaust manifold **18**. The increased separation, as already explained, will increase the amount of heat transferred to the cylinder wall. Accordingly, there is provided a control system for regulating the angular separation between burner **11** and exhaust manifold **18**. This system, like the one disclosed in the aforesaid Davis patent, includes an input slidewire **112**. A movable contact **112***a* is adjusted in response to change in the flow of air through the line **88**. A flow meter **113** is included in this line and through mechanical connections **114**, **115** drives the movable contact **112***a*. Accordingly, the input signal to an amplifier **116** which controls the energization of a motor **117** has a magnitude dependent upon the rate of flow of fuel to the cylinder **10**.

The motor **117**, through a drive sprocket **120**, a driving chain **121**, and a sprocket **122**, rotates the burner **11** about the axis of cylinder **10** to change its angular position relative to the exhaust manifold **18**. If desired, there may

be provided a mechanical connection from motor **117** as through the gears **123**, a sprocket **124**, a chain **125**, and a sprocket **126** for rotating the exhaust manifold **18** about the axis of cylinder **10** for concurrent adjustment to vary the angular separation between burner **11** and manifold **18**.

It may here be observed that the fuel and air line **14** extends telescopically within fuel and air supply line **14***b*, the overlapping portion shown at **85***a* having suitable packing to prevent leakage. A similar arrangement is provided for the outlet or exhaust line **21** as indicated by the overlapping or telescopic relationship of the line **21** with the line **21***b* as indicated at the region **85***b*. It is to be further noted that there is provided a pair of bearings for the lines **14** and **21** so that the burner **11** and the manifold **18** are both cantilever-supported within cylinder **10**.

While the arrangement of the lengths of flexible pipe as shown in FIG. 3 will be preferred, the present arrangement has been illustrated to indicate a further modification. When flexible couplings are included to provide for the angular adjustment of the burner **11** and manifold **18**, the limit switches of said Davis patent (as shown therein at 82 and 86) will be provided with each of them set for the respective limits of rotation for the burner and manifold.

By increasing the area of the heat-transferring surface with increase of heat load on the cylinder **10** and as the fuel supply is increased to take care of that load, there will result a transfer of a greater amount of heat without substantial decrease in the efficiency of operation of the system. More particularly, for a selected set point, for example, the aforesaid 600° F., there will be a dependent relation between various heat loads imposed upon the cylinder **10** and the angular separation between the burner **11** and the exhaust manifold **18**. For a 50% heat load, the separation distance will be made the optimum, i.e., for maximum efficiency in terms of heat input to the cylinder. The control **116** will thereafter vary the angular separation to maintain high efficiencies with change in heat load in either direction.

As fuel is delivered to cylinder **10** at greater rate, the quantity of products of combustion will increase and it will, accordingly, be desirable to increase the suction to the manifold **18**, both to take account of the larger quantity of combustion products as well as the increased separation distance between burner **11** and suction manifold **18**. Accordingly, as the heat load on the cylinder **10** is increased and there is a resultant change in rate of flow of fuel, as indicated by a change in the rate of flow of air as detected by the flow meter **113**, a suction-controlling valve **130** is automatically positioned to increase the suction with increase of load and to decrease the suction with decrease of load. This adjustment is made automatically by means of a motor **131** whose energization is under the control of an amplifier **132** having in its input circuit a slidewire **133** with its movable contact **133***a* adjusted by way of the mechanical connection **114** extending from the flow meter **113**. In general, it will be preferred that the control system **131—132** (like that of the aforesaid Davis patent) be primarily a proportional system, i.e., one that sets minimum suction for a minimum rate of fuel delivery to the cylinder **10** and maximum suction for a maximum rate of fuel delivery to the cylinder **10**.

The control system of said Davis patent also includes an adjustment for the extent of change of position of valve **130** for a given change in output from the flow meter **113**. Thus, the characteristics of a particular cylinder **10** in a given application can be readily taken into account by the control system to maintain high efficiencies of operation through wide changes of heat load on the cylinder at widely differing set point temperatures. In some instances, it may be desirable automatically to position the valve **30***a* in the cooling-air inlet line **30**. In such event, a thermocouple **150** responsive to the products of combustion issuing from cylinder **10** can control the positioning of the valve by way of an amplifier **151** and a motor **152** which increases the opening of the valve with increase of temperature and reduces the opening of the valve with decrease of temperature. These provisions will be particularly desirable for the fully automatic system of control.

It is to be understood that in many applications it will be entirely satisfactory manually to set the angular relationship between burner **11** and exhaust manifold **18**, and likewise manually to position the suction valve **130** and the cooling-air inlet valve **30***a*, since the load changes which may occur through long periods of operation may not be sufficiently great as to justify the expense of the added control equipment.

From the foregoing, it will be seen that the variable-area heat-transferring apparatus may be manually, automatically, or semi-automatically controlled, depending upon the requirements of particular applications. It is to be further understood that the electrical control mechanisms illustrated may be replaced by pneumatic control devices which are in general use in the combustion field. The amplifier and control motors have been illustrated as symbolic of conventional control mechanisms responsive to temperature and utilized for the positioning of valves and flow-controlling devices.

Where still higher rates of heat transfer are desired and for still higher temperatures, upwardly of about 900° F., it will be desirable to provide fluid-cooled supply lines for the pre-mixed fuel and air, since the temperatures within the cylinder will be quite high. In other words, the fuel lines will be jacketed for circulation of cooling fluid to maintain the pre-mixed fuel and air below the combustion point. By reason of the high heat transfer rates attainable, there is realized a considerable reduction in the number of drying rolls required for a given installation. For example, where 40 or 50 steam heated drying rolls are now required in paper making, the number may be reduced to 15 or 20 with a corresponding decrease in required floor space for a given paper-treating system.

In the preferred embodiment described above in connection with FIGS. 3–7, the cylinder had a diameter of 48", a length of 54". The cylinder rotated at 50 r.p.m. It was this apparatus that has developed transfer rates as high as 30,000 B.t.u.'s per hour per square foot of cylinder surface and at unexpectedly high efficiency, approaching 70%. The reference to each square foot of the cylinder surface is to the entire internal cylindrical surface and is not limited to the area of the concave surface over which the hot combustion products flow. Where the requirements are for cylinders of still greater diameter, it is contemplated that additional burners and suction heads may be provided, each pair to operate over a different segment of internal concave surface, and each pair to be angularly adjustable as described above over its own allocation of the curved heating member or cylinder.

What is claimed is:

1. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the internal curved surface of said cylinder and products of combustion within said cylinder, which comprises directing burning high velocity streams of pre-mixed fuel and air at a substantial angle to the internal curved surface along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along the curved inner surface of the cylinder, whereby the initial velocity of said pre-mixed fuel and air and the expansion of the gases incident to the combustion thereof maintains the high initial ve-

locity throughout a large circumferential area of the cylinder, applying suction across the arcuate path traversed by the products of combustion for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and regulating the angular spacing between the points of initiation of said burning streams and said region of withdrawal in accordance with change in a variable affecting the transfer of heat to said cylinder.

2. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the internal curved surface of said cylinder and products of combustion within said cylinder, which comprises directing burning high velocity streams of pre-mixed fuel and air at a substantial angle to the internal curved surface along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along the curved inner surface of the cylinder, whereby the initial velocity of said pre-mixed fuel and air and the expansion of the gases incident to the combustion thereof maintains the high initial velocity throughout a large circumferential area of the cylinder, applying suction across the arcuate path traversed by the products of combustion for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and varying the suction pressure at the region of withdrawal in accordance with change in flow of said fuel and air.

3. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the internal curved surface of said cylinder and products of combustion within said cylinder, which comprises directing burning high velocity streams of pre-mixed fuel and air at a substantial angle to the internal curved surface along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along the curved inner surface of the cylinder, whereby the initial velocity of said pre-mixed fuel and air and the expansion of the gases incident to the combustion thereof maintains the high initial velocity throughout a large circumferential area of the cylinder, applying suction across the arcuate path traversed by the products of combustion for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, concurrently regulating the angular spacing between the points of initiation of said burning streams and said region of withdrawal, and varying the suction pressure at the region of withdrawal in accordance with change in said flow of fuel and air.

4. The method of heating a hollow cylinder at high rate which comprises directing a plurality of streams of burning pre-mixed fuel and air along the length of the cylinder and in close proximity to the internal curved surface thereof and at an angle to said internal curved surface for developing tangentially directed forces to maintain the hot products of combustion along and in intimate contact with said internal curved surface, rotating said cylinder in a direction opposite to the directed travel path of said flame and hot products of combustion to increase the rate of transfer by convection of heat to said hollow cylinder by way of the internal curved surface thereof, withdrawing tangentially of the cylinder the products of combustion in a region of reduced pressure and adjacent said inner curved surface, and regulating the spacing between the points of initiation of said streams and said region of low pressure to produce continuous flow of the products of combustion along said internal curved surface and thence into said region of low pressure.

5. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the internal surface of said cylinder and products of combustion within said cylinder, which comprises directing burning high velocity streams of pre-mixed fuel and air at a substantial angle to the inner surface along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of said cylinder and in close proximity to said internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along the curved inner surface of the cylinder, whereby the initial velocity of said pre-mixed fuel and air and the expansion of the gases incident to the combustion thereof maintains the high initial velocity throughout a large circumferential area of the cylinder, rotating said cylinder to move said internal surface in counterflow to that of all of said products of combustion to produce a turbulent wiping and scrubbing action of said products of combustion against said surface, and applying suction for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface.

6. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the curved inner surface and products of combustion within said cylinder, which comprises directing burning streams of pre-mixed fuel and air at a substantial angle to said curved inner surface along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along said curved inner surface of the cylinder to develop centrifugal forces urging said combustion gases outwardly against said curved internal surface, the expansion of the gases incident to the combustion thereof maintaining a high velocity of said gases throughout a large circumferential area of the cylinder, rotating said cylinder to move said curved inner surface in counterflow to said products of combustion to cause the adjacent surface layer of said products of combustion to be in turbulent flow, and applying suction for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface.

7. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the curved inner surface and products of combustion within said cylinder, which comprises directing burning streams of pre-mixed fuel and air at a substantial angle to said curved inner surface and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along said curved inner surface of the cylinder to develop centrifugal forces urging said combustion gases outwardly against said curved internal surface, the expansion of the gases incident to the combustion thereof maintaining a high velocity of said gases throughout a large circumferential area of the cylinder, rotating said cylinder to move said curved inner surface in counterflow to said products of combustion to cause the adjacent surface layer of said products of combustion to be in turbulent flow, applying suction for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and regulating the angular spacing between the points of initiation of said burning streams and said region of withdrawal in accordance with change in flow of said fuel and air.

8. The method of heating a hollow cylinder at rates not limited by the presence of an insulating layer of air between the curved inner surface and products of combustion within said cylinder, which comprises directing burning streams of pre-mixed fuel and air at a substantial angle to said curved inner surface along a path which is angularly displaced from a radial line of said member for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along said curved inner surface of the cylinder to develop centrifugal forces urging said combustion gases outwardly against said curved internal surface, the expansion of the gases incident to the combustion thereof maintaining a high velocity of said gases throughout a large circumferential area of the cylinder, rotating said cylinder to move said curved inner surface in counterflow to all of said products of combustion to cause the adjacent surface layer of said products of combustion to be in turbulent flow, applying suction for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and varying the suction pressure at the region of withdrawal in accordance with change in flow of said fuel and air.

9. The method of transferring heat to a load by way of the wall of a hollow cylinder at rates not limited by the presence of an insulating layer of air between the curved inner surface and products of combustion within said cylinder, which comprises directing burning streams of pre-mixed fuel and air at a substantial angle to said curved inner surface along a path which is angularly displaced from a radial line of said member for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to said curved internal surface, constraining the flow path of the burning streams of pre-mixed fuel and air along said curved inner surface of the cylinder to develop centrifugal forces urging said combustion gases outwardly against said curved internal surface, the expansion of the gases incident to the combustion thereof maintaining a high velocity of said gases throughout a large circumferential area of the cylinder, rotating said cylinder to move said curved inner surface in counterflow to said products of combustion to cause the adjacent surface layer of said products of combustion to be in turbulent flow, applying suction for withdrawing the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and concurrently regulating the angular spacing between the points of initiation of said burning streams and said region of withdrawal and the suction pressure at the region of withdrawal in accordance with change in heat load on said cylinder.

10. A heating system comprising a hollow cylinder, a fuel burner having a plurality of fuel-directing jets disposed adjacent the concave internal surface of the cylinder and inclined at an angle with respect thereto for imparting to jets of burning pre-mixed fuel and air a large tangential velocity in the region in which the burning pre-mixed fuel and air impinges upon said surface, an exhaust manifold with inlet means distributed along and adjacent said surface, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow tangentially therein of the products of combustion moving along said concave surface, end-closure members for said cylinder each including a head having a circular array of openings spaced inwardly from the periphery thereof, hollow journals for rotary support of said cylinder, a plurality of radially extending gusset plates intermediate said openings secured to and extending along the inner face of each head and to said journals, and a heat-flinger assembly comprising a plate made of high heat conductivity material secured to each head and acting as a closure for each said opening and having a plurality of air-impeller elements extending outwardly from said plate for producing a flow of air between the impeller plates and in heat exchange with said plate and said head, said heat flingers terminating in spaced relation with said journals for producing a flow of air along said journals and into and along the space between said heat flingers.

11. A heating system comprising a hollow cylinder, a fuel burner having a plurality of fuel-directing jets disposed adjacent the concave internal surface of the cylinder and inclined at an angle with respect thereto for imparting to jets of burning pre-mixed fuel and air a large tangential velocity in the region in which the burning pre-mixed fuel and air impinges upon said surface, an exhaust manifold with inlet means distributed along and adjacent said surface, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow tangentially therein of the products of combustion moving along said concave surface, rotary supporting means for rotation of said cylinder about its longitudinal axis, means for rotating said cylinder, a supply pipe for said fuel burner displaced from said longitudinal axis and extending through said rotary supporting means, said supply pipe within said cylinder having an offset, a T-fitting connected to said offset portion of said supply pipe and located coaxially of said cylinder, said exit passage being coaxial with said cylinder and including a pipe having structure adjacent one end thereof forming with structure carried by said T-fitting a bearing, and means for bodily rotating with respect to each other said fuel burner and said exhaust manifold.

12. A system of heating a hollow cylinder for transfer of heat through the wall thereof to a heat load, which comprises a fuel burner, means for supplying said fuel burner with pre-mixed fuel and combustion air, said burner having a plurality of fuel-directing jets disposed lengthwise of the cylinder and adjacent the internal surface thereof and inclined at an angle for producing along said internal surface flow of burning fuel and hot products of combustion, the combustion of said pre-mixed fuel producing flow of said products of combustion at substantial velocity in intimate heat exchange with said internal surface, means for rotating said cylinder in a direction counter to the flow of said products of combustion for inducing a multiplicity of eddy currents and swirls within the region adjacent said internal surface to increase the rate of heat transfer thereto, said angular disposition of said fuel jets and said curved inner surface giving rise to centrifugal forces, applying to said swirls and eddy currents forces which tend to maintain them in intimate contact with said inner surface, an exhaust manifold with inlet means distributed lengthwise of said cylinder and adjacent said internal surface of said cylinder, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow of said products of combustion into said manifold adjacent said surface, means for applying suction to said manifold for forced flow of combustion products therein and for development of forces tending to maintain the flow of said combustion gases along said inner surface, and means responsive to the heat load for adjusting said angular separation in accordance with change in said heat load.

13. A system of heating a hollow cylinder for transfer of heat through the wall thereof to a heat load, which comprises a fuel burner, means for supplying said fuel burner with pre-mixed fuel and combustion air, said burner having a plurality of fuel-directing jets disposed lengthwise of the cylinder and adjacent the internal surface thereof and inclined at an angle for producing along said internal surface flow of burning fuel and hot products of combustion, the combustion of said pre-mixed fuel producing flow of said products of combustion at substantial velocity in intimate heat exchange with said internal surface, means for rotating said cylinder in a di-

rection counter to the flow of said products of combustion for inducing a multiplicity of eddy currents and swirls within the region adjacent said internal surface to increase the rate of heat transfer thereto, said angular disposition of said fuel jets and said curved inner surface giving rise to centrifugal forces applying to said swirls and eddy currents forces which tend to maintain them in intimate contact with said inner surface, an exhaust manifold with inlet means distributed lengthwise of said cylinder and adjacent said internal surface of said cylinder, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow of said products of combustion into said manifold adjacent said surface, means for applying suction to said manifold for forced flow of combustion products therein and for development of forces tending to maintain the flow of said combustion gases along said inner surface, means for relatively adjusting the angular separation between said fuel burner and said exhaust manifold, and means responsive to the heat load for adjusting said angular separation in accordance with change in said heat load and for concurrently adjusting the suction applied to said manifold for developing maximum heat transfer for a given rate of fuel supply to said burner.

14. A system of heating a hollow cylinder for transfer of heat through the wall thereof to a heat load, which comprises a fuel burner, means for supplying said fuel burner with pre-mixed fuel and combustion air, said burner having a plurality of fuel-directing jets disposed lengthwise of the cylinder and adjacent the internal surface thereof and inclined at an angle for producing along said internal surface flow of burning fuel and hot products of combustion, the combustion of said pre-mixed fuel producing flow of said products of combustion at substantial velocity in intimate heat exchange with said internal surface, means for rotating said cylinder in a direction counter to the flow of said products of combustion for inducing a multiplicity of eddy currents and swirls within the region adjacent said internal surface to increase the rate of heat transfer thereto, said angular disposition of said fuel jets and said curved inner surface giving rise to centrifugal forces applying to said swirls and eddy currents forces which tend to maintain them in intimate contact with said inner surface, an exhaust manifold with inlet means distributed lengthwise of said cylinder and adjacent said internal surface of said cylinder, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow of said products of combustion into said manifold adjacent said surface, means for applying suction to said manifold for forced flow of combustion products therein and for development of forces tending to maintain the flow of said combustion gases along said inner surface, means for relatively adjusting the angular separation between said fuel burner and said exhaust manifold, and means for adjusting the area of the internal surface in contact with said hot products of combustion in accordance with the magnitude of the flow of fuel to said burner and for increasing said area with increase in said magnitude and for decreasing said area with decrease of said magnitude.

15. A system of heating a hollow cylinder for transfer of heat through the wall thereof to a heat load, which comprises a fuel burner, means for supplying said fuel burner with pre-mixed fuel and combustion air, said burner having a plurality of fuel-directing jets disposed lengthwise of the cylinder and adjacent the internal surface thereof and inclined at an angle for producing along said internal surface flow of burning fuel and hot products of combustion, the combustion of said pre-mixed fuel producing flow of said products of combustion at substantial velocity in intimate heat exchange with said internal surface, means for rotating said cylinder in a direction counter to the flow of said products of combustion for inducing a multiplicity of eddy currents and swirls within the region adjacent said internal surface to increase the rate of heat transfer thereto, said angular disposition of said fuel jets and said curved inner surface giving rise to centrifugal forces applying to said swirls and eddy currents forces which tend to maintain them in intimate contact with said inner surface, an exhaust manifold with inlet means distributed lengthwise of said cylinder and adjacent said internal surface of said cylinder, said inlet means disposed generally tangentially of said cylinder and facing toward said jets for flow of said products of combustion into said manifold adjacent said surface, means for applying suction to said manifold for forced flow of combustion products therein and for development of forces tending to maintain the flow of said combustion gases along said inner surface, control means responsive to a temperature at a selected location on said cylinder for controlling said fuel supply means to increase the rate of fuel supply with decrease of temperature and for decreasing said rate of fuel supply with increase in said temperature, and control means responsive to said change in said rate of said fuel supply for concurrently varying the area of said internal surface over which said hot products of combustion flow in heat transfer therewith to increase said area with increase in said rate of fuel supply and to decrease said area with decrease in said rate of fuel supply.

16. Heat-transfer means comprising a hollow cylinder, means for heating at least a portion of the internal surface of said hollow cylinder at rates not limited by the presence of an insulating layer of air between the internal curved surface of said cylinder and products of combustion within said cylinder comprising a fuel burner for directing burning high velocity streams of pre-mixed fuel and air at a substantial angle to the internal curved surface of said cylinder along a path which is angularly displaced from a radius of said cylinder for development of substantial forward velocity of all of said burning fuel and air and in a zone extending lengthwise of the cylinder and in close proximity to its said curved internal surface, said cylinder constraining the flow path of the burning streams of pre-mixed fuel and air along said curved inner surface whereby the initial velocity of said pre-mixed fuel and air and the expansion of the gases incident to the combustion thereof maintains the high initial velocity throughout a large circumferential area of the cylinder, means including a suction head extending across the arcuate path traversed by the products of combustion for applying suction for withdrawal of the products of combustion tangentially of said cylinder in a region extending lengthwise of said cylinder and adjacent said surface, and means responsive to a change in a variable affecting said rate of transfer of heat to said cylinder, said means including pivotal mounting structure, for relatively angularly changing the separation distance between said fuel burner and said suction head to regulate the size of the area over which there is a high rate of transfer of heat to said cylinder.

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