A method of drying a solvent type coating on a surface, by heating the coating within an oven by a hot gaseous medium and in which the gases within the oven are continuously exhausted, and the effluent gases leaving the oven are then separated into two streams, namely, a recyle stream and an oxidation stream, and in which the oxidation stream is then passed through an oxidizer where the solvent vapours in the oxidation stream are then oxidized by burning or by catalytic action. The recycle stream of untreated effluent gases is then recycled directly into the oven once more without passing through the oxidizer at all. The combustion gases leaving the oxidizer are then separated into two streams, and one stream is vented to atmosphere. The other stream, namely a return stream, is then passed into the oven again together with the recyle stream of unburnt effluent gases. Sufficient fresh air is drawn into the system, preferably through a heat exchanger heated by the waste combustion gases, and such additional make-up air is then passed directly into the oven, where it mixes with the incoming return stream of combustion gases, and the incoming recyle stream of unburnt effluent gases to maintain the desired process temperature. The specification also discloses apparatus suitable for the practising of the method.

8 Claims, 2 Drawing Figures
Inventor

DWIGHT M. WILKINSON

by: George A. Rolston
COMBUSTION OF EFFLUENT GASES
700°F to 1600°F.

20 to 30% of EFFLUENT GASES
AT 150°F to 900°F.

HEAT TRANSFER
FROM COMBUSTION
GASES TO INCOMING
FRESH AIR.

95 to 45% COMBUSTION GASES
AT 700°F to 1600°F.

5 to 35% COMBUSTION GASES
AT 700°F to 1600°F.

MAKE UP AIR
AMBIENT TO 800°F.

EFFLUENT GASES
AT 150°F to 900°F.

70 to 80% EFFLUENT GASES
AT 150°F to 900°F.

COMBINED OVEN
HEATING & DRYING
GASES AT
200°F to 1000°F.

oven
(temp: 200° to 1000°F).

Inventor
Dwight M. Wilkinson

by: George A. Polston.
METHOD AND APPARATUS FOR DRYING SOLVENTS

The present invention relates to a method of drying a solvent type coating such as paint, adhesive, and the like after application thereof to a workpiece, and to apparatus therefor.

BACKGROUND OF THE INVENTION

The drying of such coating composition, on a continuously moving production line, has in the past, been carried out by means of one or more drying ovens arranged around a production line, designed to heat and evaporate the solvent under controlled conditions. In most cases, the evaporated solvent gases are continuously evacuated from the oven or ovens and vented to atmosphere. More recently, with a view to reducing costs, and reducing environmental pollution, by release of such solvents into the atmosphere, provision has been incorporated in such systems to pass the solvent vapour laden exhaust gases from the oven through a burner, or catalytic converter, which oxidize the solvents by burning them before releasing them to the atmosphere. In certain cases, the heat generated by such solvent vapour oxidation has been employed to preheat the incoming air before it is drawn into the oven, and in addition, it has been proposed to actually recycle a portion of the combustion gases released from the burner together with the incoming fresh air so as to achieve still greater economy. Examples of such systems are shown in U.S. Pat. No. 4,373,211 dated Apr. 8, 1989, Dwight M. Wilkinson, and also in U.S. Pat. Nos. 2,804,694; 3,106,386; 3,183,605; and in U.K. Letters Patent Nos. 990,873; 1,027,732; 822,244 to give only a few examples. However, in all of these devices, it was proposed that substantially all of the effluent gases removed from the oven would be passed through the burner, with the result that it was necessary to provide a burner of a very substantial capacity. Such a burner, when made of sufficient size would be excessively costly both to build and to operate, consuming excessive quantities of burner fuel, or requiring replacement of costly catalysts. In addition, since in order to support such oxidation of the solvent vapours, it is necessary to provide substantial quantities of fresh air, the incoming gas mixture was at too low a temperature, and was frequently further pre-heated prior to introduction into the furnace. In addition, such previous proposals incorporated some supplementary form of heating means within the oven such as radiant heaters or the like, so as to apply sufficient heat to the workpiece as it passes through the oven to ensure rapid evaporation of the solvent. In addition, although such systems did succeed in removing a substantial quantity of the solvent vapours from the waste gases, they did not always operate at maximum efficiency, and in addition, there were very substantial heat losses to atmosphere. One of the factors resulting in the inefficiency of such previous proposals was the fact that the rate at which the solvent could be vaporized and entrained with the gases passing through the oven, was quite small in relation to the mass of gases passing through the oven, and in fact, only relatively minor amounts of solvent vapours were removed in proportion to total gas flow. As a result, the total gas flow required to pass through such oven was found to be very large indeed in order to achieve a reasonable operating speed for the movement of the production line through the oven. Thus, either the production line had to move very slowly or alternatively, the oven had to be much longer than was economically feasible, or alternatively the rate of gas flow through the oven had to be still further increased, out of all proportion to the economics of the system. In addition, as the total volume of gas flowed through the oven system was increased, the size of the burner or catalytic converter was correspondingly increased, and its operation became even more uneconomic. In addition, the very large gas flows involved, to make the system economic, resulted in a substantial temperature drop across the oven, requiring additional and excessive heat input from the source within the oven, and also requiring additional heat input prior to introduction of the gases into the oven, to bring them up to a reasonable operating temperature.

In fact, in such systems, the concentrations of solvent vapours present in the total gas mass passing through the system is in the order of a small fraction of a percentage, and is in any event at a predetermined margin below the accepted maximum safety limits laid down for most of solvents concerned. Thus, in the case of, for example, toluol, the normal lower explosive limit of concentration of toluol vapours in air is somewhere in the region of about 1.3 percent. Generally accepted safe engineering practice, requires that when handling mixtures of air and such vapours, the concentration should be kept at somewhere in the region of about one-quarter of the lower explosive limit, i.e., about 0.3 of one percent concentration. Thus, in such earlier systems, notwithstanding the large air flow through the oven, the rate of solvent vapour removal, for a given gas flow, could not exceed these limits, i.e., about 25 percent of the L.E.L. of the solvent involved. As a result, compared with the burner capacity, horsepower, and additional heat input required, the overall efficiency of the system was quite low.

In addition, while it was known that a very substantial proportion of the heat from the combustion gases leaving the burner or converter was wasted by venting to atmosphere, any attempt to use a larger proportion of such gases in the oven, to evaporate the solvent to a greater degree was found to involve still more difficulties since a certain minimum of fresh air must always be drawn into the system to support oxidation of the solvent vapours. Thus, as more combustion gases are recycled, more fresh air must be added. In addition, while it is a well known engineering principle, that the efficiency of heat transfer from a fluid medium to a heat transfer surface, is proportional to the rate of movement of such fluid medium in relation to such surface, and also to the turbulence of such medium. The slower the moveMent of such fluid medium, the greater is the tendency for a so-called “boundary layer effect” to build up which effectively insulates the surface from the heat present in the main body of the fluid medium, and greatly reduces the efficiency of the heat transfer. However, as the relative speed of movement of the fluid medium, in this case the gases flowing through the oven, is increased, the total volume of gases going through the burner system is increased, with consequent increases in operating expenses and engineering costs.

BRIEF SUMMARY OF THE INVENTION

The present invention seeks to overcome these vari-
ous disadvantages, and to greatly increase the efficiency of such systems, while reducing or substantially eliminating the requirement for additional heating sources within the oven, by providing a system in which the gases within the oven are continuously exhausted, and the effluent gases leaving the oven are then separated into two streams, namely, a recycle stream and an oxidation stream, and in which the oxidation stream is then passed through an oxidizer where the solvent vapours in the oxidation stream are then oxidized or burned. The recycle stream of unburned effluent gases is then recycled directly into the oven once more without passing through the burner at all. The combustion gases leaving the burner are then separated into two streams, and one stream is vented to atmosphere. The other stream, namely a return stream, is then passed into the oven again together with the recycle stream of unburnt effluent gases. Sufficient fresh air is drawn into the system, preferably through a heat exchanger heated by the waste combustion gases, and such additional make-up air is then passed directly into the oven, where it mixes with the incoming return stream of combustion gases, and the incoming recycle stream of unburnt effluent gases. By this system, the major portion of the gases within the oven is continuously recycled without any treatment whatever, such recycled gases being subjected only to heat loss as they pass through the oven which will in most cases be relatively small. A relatively smaller portion of the effluent gases are bled off to form the oxidation stream, and are passed through the burner for oxidation of the solvent vapours, and are simultaneously raised to a very substantially elevated temperature. The return stream portion of the high temperature combustion gases leaving the burner is then sufficient when mixed with the recycled gases and the fresh incoming air, to maintain the gas mixture within the oven at or within a predetermined elevated temperature range sufficient to procure rapid evaporation of the solvent vapours, generally speaking without the requirement for any additional heat input into the oven whatever.

Heating of the gas stream entering the oven, and evaporation of the solvent and curing of the coating on the workpiece is thereby achieved using only a relatively minor outside heat input, the major heat source being the heat resulting from the oxidation of the solvent vapours in the combustion stream fraction of the effluent gases. In addition, in this way, it is possible to ensure that the effluent gases leaving the oven, contain a maximum percentage of solvent vapour, at or close to the maximum engineering standards for such solvent, thereby ensuring that the entire system works at its maximum efficiency within safety requirements. The effluent gases leaving the oven are continuously monitored by any suitable gas analyser to determine at any time the solvent vapour content of such effluent gases to ensure that such safety limits are not exceeded.

In addition, the invention contemplates the provision of suitable apparatus for the practice of such method including an oven, means for flowing gases into said oven, and distributing them over the workpiece for heating the coating thereon, means for continuously removing such gases from the oven, means for separating the gases removed from the oven into two streams, means for continuously recycling one said stream of gases directly into the oven, catalytic or burner chamber means receiving the other portion of said gases for oxidizing the solvent vapours with said gases, means for separating the combustion gases from said burner into two streams, and venting one said stream to atmosphere, means for recycling the other said stream of combustion gases directly into the intake of said oven, and air intake means for introducing make-up air into said oven, and monitoring means for monitoring the solvent vapour content of the effluent gases leaving the oven.

Preferably, such apparatus according to the invention will provide for means directing the incoming hot gases directly onto the surface of the workpiece at relatively high speed, whereby to achieve high flow rates of gases over such surfaces of the workpiece, and at the same time to achieve maximum turbulence, whereby to minimize the development of a "boundary layer effect."

BRIEF DESCRIPTION OF THE DRAWINGS

Further and other related advantages and objectives will become apparent from the following description of a preferred embodiment of the invention which is given here by way of example only, and with reference to the following drawings in which like reference devices refer to like parts thereof throughout the various portions of the diagram and in which:

FIG. 1 is a schematic end elevational view of a typical drying oven according to the invention, with portions thereof sectioned to reveal their construction; and

FIG. 2 is a process flow diagram.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Before describing the process of the invention, the apparatus by which it may be performed is first shown and described.

Referring now to FIG. 1, such apparatus is seen to comprise a drying oven or chamber 10, which is partially sectioned and is shown in end elevational view, that is to say, looking straight along the production line, along the axis of movement of the workpiece. The details of the production line are not shown, but it will be understood that such a production line would consist of any means for moving a workpiece indicated in FIG. 1 by the reference w at a continuous rate through the oven 10. The workpiece may, for example, be a continuous strip of sheet metal coated with paint, in which case it will be completely unsupported throughout the length of the oven, merely passing over rollers at one end and the other. Alternatively, the workpiece may be a web of some other material to which a laminate is bonded by adhesive. Again, the workpiece may, in fact, be a series of separate items all of which have been treated in sequence with either a paint coating or lacquer, or an adhesive or the like, which requires to be cured or dried by evaporation of a solvent. In this case, of course, such separate items or workpieces would then be supported in some other way, either laying on a suitable material handling conveyor, or hung from racks on an overhead conveyor or the like in any number of different ways which are well known in the art. Obviously, if some form of overhead conveyor is employed, then various other modifications will have to be made to the interior of the oven 10, which will not depart from the scope of the invention and will be obvious to person skilled in the art.
Within the oven 10, there is provided a continuous header duct 11, running along the length of the oven 10 along one side thereof, and provided at spaced intervals with branch ducts 12 extending above and below the workpiece as shown. The branch ducts 12 are in turn provided with a plurality of spaced apart nozzles or jets 13 adapted and oriented to direct gases flowing therefrom directly down onto the surfaces of the workpiece so as to cause the same to impinge directly thereon and cause a maximum degree of turbulent gas flow, thereby inhibiting the build-up of any "boundary layer." The header duct 11 is preferably supplied with a gaseous drying medium by means of the fan system 14. Such nozzles 13 may be of any suitable design and will include slotted openings and the like.

In order to extract the gaseous effluent from the oven 10, an exhaust duct 15 is provided, and in it turn is split into a recycle duct 16, and an oxidation stream duct 17. It will be noted that the recycle duct 16 is very substantially larger than the oxidation stream duct 17 so as to ensure that the major proportion of the effluent gases are recycled, and that the lesser remaining portion is delivered to the oxidation stream duct. If desired, suitable adjustable controls and dampers can be incorporated in the ducting system to ensure the desired proportioning between the recycle duct 16 and the oxidation stream duct 17, such damper system being well known in the art and being omitted for the sake of clarity. A gas analyzer 18 is provided in the oxidation stream duct 17, preferably an infra-red spectrum analyzer, for the purpose of continuously monitoring the solvent vapour content of the effluent gases. The oxidation stream duct 17 is connected through a fan system 20 to the burner chamber 21. The burner chamber 21 is provided with a gas permeable burner screen 22, and fired by a gas burner system 23 supplied with natural gas or other suitable gas through the control valve 24.

The combustion products developed within the burner 21 will be at a substantially elevated temperature, and accordingly, the oxidation products duct 25 which removes the combustion gases from the burner 21 is of substantially larger size than the oxidation stream duct 17. Any suitable temperature gauge 19 is provided in duct 25 for continuously sensing the temperature of gases therein. The oxidation products duct 25 is itself split into two ducts. The waste duct 26 is provided to vent a predetermined proportion of the combustion products to atmosphere, passing through the heat exchanger 27 to the outlet vent stack 28. The combustion gases return duct 29, which is also connected to the duct 25, is substantially the same size as the duct 26, whereby to permit a more or less equal division of the oxidized gases flowing in duct 25 into two separate streams. The return duct 29 is then connected to the plenum chamber 30, connected in turn to the fan system 14 for return into the oven 10.

The recycle duct 16 will also be seen to be connected to the plenum chamber 30 for mixing with the return stream in the duct 29, and recycling through the oven 10. In order to provide additional make-up air, both to provide oxygen for supporting the oxidation of the solvent vapours in the burner chamber 21, and also to replace the waste gases vented through the waste gas duct 26, a fresh air inlet duct 31 is provided, connected to the plenum chamber 30, at one end, and at its other end, connected to the downstream side of the heat exchanger 27. The heat exchanger 27 is supplied at its upstream end with fresh air entering through the air inlet 32, and the air inlet duct 33, and the fan system 34. Clearly, suitable dampers may be provided in ducts 26 and 29, to proportion the splitting of the stream in the duct 25, and a suitable damper valve 35 can be supplied in the duct 29 to control the percentage of recycled oxidation gases and a similar damper 36 in duct 26 if desired.

The operation of the process according to the invention is essentially continuous, and after the start-up phase of the process, the operation will be substantially as follows:

The workpiece w will move at a predetermined rate through the oven 10, carrying on its surface, or at an interface if an adhesive is involved, a coating composition such as a paint, adhesive or the like having a solvent. The gaseous solvent drying medium, the composition of which will be described below, is at an elevated temperature, in the range suitable for the most efficient vaporization of the particular solvent involved. Bearing in mind the variation in possible solvents, such temperature range will be anywhere between 200° and 1,000° F. Such gaseous drying medium, within its predetermined temperature range, is driven by the fan system 14 into the header duct 11 and then to the branch ducts 12 where it is emitted by the jets or nozzles 13 directly onto the surfaces of the workpiece w. At these temperatures, the gaseous drying medium is itself sufficient to heat the coating material on the workpiece surfaces, and procure rapid and efficient vaporization of the solvent material therein. In particular, the large quantities of such gaseous drying medium flowing directly from the jets 13, onto the surfaces of the workpiece will procure a highly efficient transfer of heat thereto, under turbulent flow conditions, and at the same time, the large volume of gases flowing through the oven 10 will ensure the rapid entrainment and removal of all solvent vapours developed by such heat.

The gaseous medium within the oven 10, is continuously evacuated through the effluent exhaust duct 15, and following removal from the oven 10, is then split into two streams, namely an effluent recycle stream carried in the effluent recycle duct 16, and an oxidation stream carried in the oxidation duct 17. The pressure drop required to ensure such continuous full flow evacuation of effluent through the duct 15 is of course, secured in part by the operation of the fan system 14, and in part by the operation of the fan system 20 as described above.

Preferably, the effluent recycle stream is substantially larger than the oxidation stream, and in the majority of cases, the effluent stream will be somewhere between seventy and eighty percent of the total effluent gases leaving the oven, and the oxidation stream will contain the balance, i.e., somewhere between twenty and thirty percent of the effluent gases leaving the oven. The effluent gases leaving the oven will, of course, be at a temperature slightly below the temperature at which they entered the oven, i.e., somewhere between 150° and 900° F.

With regard to the oxidation stream, this stream is subjected to the control of the monitoring device 18, which continuously observes the solvent vapour content of the effluent stream passing in the duct 17. The fan system 20 drives the gases within the duct 17 into the burner system 21, where they are oxidized or
burned, by means of passing the same through a permeable screen 22, and firing the same with a natural gas flame system from the burners 23. Preferably, the action of the natural gas flame is sufficient to raise the temperature of the solvent vapours to their "auto-ignition" temperature, at which point combustion will take place spontaneously in the presence of an excess of oxygen.

The supply of natural gas to the burner will, of course, be varied so that it is just sufficient to maintain and support the auto-combustion of the solvent vapours, thereby minimizing the additional heat input. Such combustion will raise the temperature of the resulting oxidation gas products to somewhere in the region of between 1,200°F and 1,600°F thereby increasing the volume of such gases. The high temperature oxidation products are then withdrawn from the combustion chamber through the oxidation products duct 25. The temperature of such gases in duct 25 is continuously checked to ensure that the temperature within the burner remains in a predetermined range and the natural gas supply to the burner may be varied accordingly.

The oxidation products are then split into two more or less equal streams, and one stream is vented to atmosphere through the waste duct 26, which passes through the heat exchanger 27 and vents to atmosphere through the outlet 28. The other stream passes down the return duct 29, where it connects with the plenum chamber 30. In both such ducts, the temperature of the gases will be in the 1,200°F to 1,600°F range, and the proportioning between the two ducts, will be somewhere between 5 and 55 percent through the recycle duct and the balance, i.e., between 45 and 95 percent through the waste duct. In order to make up the relatively small proportion of gases vented to atmosphere through the waste duct 26, and also in order to provide sufficient free oxygen to support combustion within the chamber 21, additional fresh air is introduced into the system through the air inlet duct 31. Duct 31 is supplied with pre-heated air from the heat exchanger 27 into which air at ambient atmospheric pressure is introduced through the inlet 32, duct 33 and fan 34.

The pre-heated air flowing in the duct 31 is somewhere between 200°F and 800°F in the average process operation. However, in some cases, pre-heating of the air may be unnecessary and the incoming air will then be at ambient air temperature. Such make-up air is again communicated to the plenum 30. The mixture of gases reaching the plenum 30 is then forced by the fan 14 into the header duct 11, where it forms the gaseous drying medium entering the oven as described above. Such gaseous drying medium will, therefore, be seen to comprise a mixture consisting of:

1. Untreated recycled effluent gases to the extent of somewhere between 70 and 80 percent, and at a temperature of somewhere between 150°F and 900°F, i.e., only just below the desired processing temperature range which must be achieved within the oven 10.

2. A mixture of gases making up the balance of 30 to 20 percent and comprising:
   a. approximately 5 to 55 percent of returned oxidation gases, at a temperature range of between 1,200°F to 1,600°F or in the case of catalytic conversion between about 700°F and 900°F the terms combustion and oxidation being deemed equivalent in this discussion.
   b. between about 95 to 45 percent make-up air at between ambient temperature and 800°F.

The combined mixture will have an overall temperature higher than the recycled untreated effluent gases, and within the desired processing range and in this way, continuous provision of gaseous drying medium is achieved for the oven 10 at a temperature within its desired processing range, which gaseous medium is comprised to a very large extent of untreated recycled effluent gases from the oven itself, only a minimum portion of such effluent gases being bled off and subjected to burning for solvent removal, and only a minimum proportion of additional make-up air being added to the process at any given time. Thus, the process is highly economical in fuel consumption in the burner, and is also economical in terms of consumption of fresh air, and at the same time, conserves the overall energy in the system to a great extent since only a small proportion of high temperature burnt gases are vented to atmosphere, i.e., between say 5 and 25 percent of the overall gas flow through the oven at any time.

It will of course, be understood that the process according to the invention when applied to any particular solvent, will be so designed and engineered as to operate at or near the maximum safe solvent vapour content, i.e., somewhere between 25 to 35 percent of the lower explosive limit of concentration of the particular solvent. Obviously, in order to ensure that the process works continuously within this range, the process is so engineered that the gaseous drying medium entering the oven through the plenum, contains solvent vapours sufficiently below such safe maximum limit that the additional solvent vapours which are entrained with such gases as they pass through the oven, do not bring the concentration of solvent vapours in the effluent leaving the exhaust above such safe limit. Obviously, if the concentration of solvent vapours exceeds the safe maximum limit, then it is possible to make certain minor variations in the process to correct the condition. Thus, for example, the speed at which the workpiece or other material carrying the coating layer is passed through the oven can be reduced, thereby providing a somewhat smaller quantity of solvent available for vaporization by the gaseous medium passing through the oven, at any given time. Alternatively, alterations can be made in the composition of the coating material prior to entry to the oven so as to reduce the concentration of solvent therein, or possibly so as to reduce the thickness of the coating if this can be achieved without damage to the end product. It is to be particularly noted that in the present process, since there is no provision of an additional heat source such as radiant heating means within the oven, that the slowing down of the production line can, in fact, be achieved safely without damage to the coating layer or the workpiece in a great majority of cases. In the past, when ovens were customarily provided with radiant heaters directly heating the workpiece, the speed of movement could not be reduced without burning off or damaging the coating layer or the workpiece.

In the great majority of cases, the heat supplied by the oxidation of a small proportion of the effluent gases, in accordance with the process according to the present invention, will provide sufficient additional heat to ensure that the combined gaseous drying medium entering the oven through the plenum will be within the desired processing range. However, in the event that in any particular case, such heat is insufficient, then it may be possible to provide for a small de-
gree of additional heating by the provision of a supplementary burner within the plenum (not shown) although this is usually found to be unnecessary.

Further in accordance with the process according to the invention, in order to provide for safe operation, and in order to ensure that the safe maximum concentrations of vaporized solvent are not exceeded, the effluent stream exiting from the oven is continuously monitored by a gas analyser, such as an infra-red gas spectrometer or the like, which gives a continuous reading of the solvent vapour content of such effluent. In addition, the temperature of the oxidation gases is also continuously monitored. Suitable warning lights and automatic cut-outs are provided (not shown) whereby plant personnel may be warned of any dangerous rise in concentration, and whereby the entire process may be shut down in the event of such a dangerous concentration continuing.

It should be noted that the upper and lower limits of the proportions of different gases in the various gas streams, are more or less well defined, and are selected to provide for the maximum efficiency of operation, at a minimum of heat input and horsepower consumption. Thus, the splitting of the effluent stream exhausted from the oven into a recycled effluent gas stream of between 70 and 80 percent, and an oxidation gas stream of between 20 and 30 percent, is determined by the fact that it is found that if more than thirty percent of the effluent gases are oxidized by passing through the burner chamber or a catalytic oxidation chamber, the percentage concentration of solvent vapours present in the effluent will gradually drop below the desired range of the between 25 and 35 percent of the L.E.L. of the solvent, thereby reducing the efficiency of the system. On the other hand, if less than about twenty percent of the effluent is passed through the oxidation chamber, then the percentage of solvent vapours will gradually rise above the safety limit, causing frequent shutdowns. In addition, the combustion or oxidation gases exiting from the oxidation or burner chamber will in certain circumstances become insufficient to satisfy the requirements both for returning a portion of such combustion gases directly to the plenum, and passing the remaining portion through the heat exchanger, and additional heat input may be required in the plenum to bring the gaseous drying medium up to the desired processing range.

The percentage range of blending between returned oxidation gases, and fresh air, is itself determined by the requirements for, on the one hand, the most efficient combustion or oxidation in the burner, and on the other hand, for the maintenance an adequate heat input into the gaseous drying medium in the plenum 30, sufficient to maintain such gas mixture within the predetermined processing range. Thus, in order to support oxidation or combustion, in the burner chamber, it is essential that there shall be not less than sixteen percent of free oxygen. If the free oxygen drops below this percentage, then oxidation will be incomplete, and carbon monoxide gases will be formed, which will themselves lower the lower explosive limit of the effluent mixtures, and reduce the efficiency of the system. On the other hand, it is not found to be practical to return much less than about five percent of the combustion gases into the plenum 30, since such a percentage is about the minimum which will maintain an adequate processing temperature in the gas mixture forming in the plenum.

It will of course be understood that when operating at a lower processing temperature in the oven, then a smaller volume of combustion gases will be returned to the plenum, and with processes requiring a higher operating temperature, then greater volumes of such gases will be required, it being again understood that depending upon the type of processing and the type of solvent involved, a very low temperature process will require the return of somewhere between, say 5 and 15 percent of the combustion gases, and a process requiring a very high temperature in the oven will require the return of combustion gases in the region of 45 to 55 percent.

By way of illustration of the process, three examples are now given showing the application of the process to three typical production lines.

EXAMPLE 1

A typical low temperature process would be the drying of a solvent dispersed adhesive in a laminating process. In such a production line, the adhesive may be applied by roller coating, curtain coating, spray coating and the like, and the solvents are evaporated in an oven. Typically, the operating temperatures of such a process will be in the range of between about 200° and 400°F. On the assumption that oxidation of the oxidation stream of the effluent gases will be achieved in a burner chamber, resulting in the creation of very high temperature combustion gases, then approximately between about 5 and 25 percent of the volume of combustion gases would be returned to the plenum to sustain the processing temperature, the balance being provided by the fresh air. Obviously if in this example, oxidation is achieved by means of a catalytic oxidation process, then the gases in such chamber would be at a substantially lower temperature, i.e., 700° to 900°F. As opposed to 1,200° to 1,600°F in the case of a burner. In this case, a somewhat greater percentage of the oxidation gases would then be returned to the plenum in order to sustain the desired temperature.

EXAMPLE 2

A process in the intermediate temperature range will be, for example, the evaporation of a solvent from glass fibre material after impregnation with resin. The processing temperature within the oven would be between 300° and 600°F, and between about 15 and 35 percent of the oxidation gases would normally be required to be returned to the plenum to sustain the desired operating temperature range in the gaseous drying medium.

EXAMPLE 3

A process in the higher temperature range will be the drying of paints or lacquers on a sheet metal coating production line. In this process, the temperatures in the oven will be in the range of 350° to 900° F and between about 15 and 55 percent of the oxidation gases will be returned to the plenum in order to sustain the desired processing temperature in the oven.

Further by way of explanation, examples of a few selected solvents are now set out together with their characteristics.
SOLVENT PROPERTIES AND SOLVENT COMPOSITIONS

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<tr>
<th>Solvent Type</th>
<th>Initial Boiling Point (°F)</th>
<th>Dry Point (°F)</th>
<th>Auto Ignition Point (°F)</th>
<th>Explosive Limit lower</th>
<th>Explosive Limit upper</th>
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The foregoing is a description of a preferred embodiment of the invention which is given here by way of example only. The invention is not to be taken as limited to any of the specific features described, and comprehends all such variations thereof which come within the scope of the invention.

What I claim is:

1. The method of drying a solvent type coating composition such as paint after application thereof to both sides of a workpiece, by continuous evaporation and oxidation of said solvent comprising the steps of:
   passing said coated workpiece through an oven;
   continuously flowing a gaseous drying medium through an inlet fan system into said oven at an elevated temperature in a predetermined range adequate to procure rapid evaporation and entrainment of said solvent into said gaseous medium, said gaseous medium being discharged within said oven at spaced apart points located on both sides of said workpiece and directed onto both said sides whereby to procure turbulent gas flow on both said sides and maximize heat transfer to said coating thereon;
   continuously withdrawing gaseous effluent from said oven, said effluent comprising said gaseous medium and said entrained vaporized solvent to procure full flow thereof through said oven;
   separating said effluent into an oxidation stream comprising between 20 and 30 percent of said effluent and a recycle stream comprising between 70 and 80 percent of said effluent;
   recycling said recycle stream directly back into said oven through said inlet fan system;
   passing said oxidation stream through a fan system into an oxidation chamber and elevating the temperature thereof and procuring oxidation of said vaporized solvent in the presence of sufficient free oxygen to support said oxidation whereby to heat said effluent and convert the same into gaseous products of oxidation at an elevated temperature in excess of said recycled stream of effluent;
   maintaining said recycle stream separated from said oxidation chamber whereby the temperature of said recycle stream remains substantially unchanged during recycling;
   separating said oxidation products into a waste stream and a return stream;
   passing into said inlet fan system said recycled stream of said effluent and said return stream of said oxidation products and adding air thereto to form said gaseous drying medium within said oven, said return stream of oxidation products mixing with said recycled stream of effluent and said air and raising the temperature thereof whereby said gaseous drying medium is maintained in said predetermined elevated temperature range; and,
   continuously analyzing the effluent from said oven between said oven and said oxidation chamber to determine the content of vaporized solvent in said effluent prior to oxidation thereof.

2. The method of drying a solvent type coating as claimed in claim 1, wherein said gaseous drying medium comprises a mixture of gases consisting of between about seventy and eighty percent of said recycled effluent gases at a temperature slightly below said predetermined process range, and the balance of between 30 and 20 percent of said gaseous drying medium comprising a mixture of between about 5 and 55 percent of said oxidation products, and between about 95 and 45 percent of fresh air.

3. The method of drying a solvent type coating as claimed in claim 1, wherein said gaseous effluent withdrawn from said oven contains entrained vaporized solvent in a concentration of between 25 and 40 percent of the lower explosive limit of concentration of said solvent.

4. The method of drying a solvent type coating as claimed in claim 1, wherein said oxidation stream of effluent gases is oxidized by passing the same through a burner means to raise the temperature therein to at least the auto-ignition temperature of said vaporized solvent in said oxidation stream.

5. The method of drying a solvent type coating as claimed in claim 1 including the step of pre-heating said fresh air, by passing the same through a heat exchanger, heated by said waste stream of oxidation gases.

6. Oven drying apparatus for the continuous evaporation of a solvent type coating composition after application thereof to a workpiece, having two sides and oxidation of such solvents prior to venting the same to atmosphere and comprising:
   drying oven means;
   means for moving said coated workpiece continuously through said oven means;
   inlet fan means for forcing large volumes of a gaseous drying medium into said oven at an elevated temperature within a desired processing range;
   discharge means having a plurality of outlets spaced from one another for flowing said gaseous drying medium directly onto said workpiece from both sides thereof and procuring turbulent flow over the surfaces thereof, whereby to ensure efficient transfer of heat thereto and evaporation and entrainment of said solvent into said gaseous medium;
   an exhaust outlet for continuously removing a gaseous effluent, from said oven, comprising said gaseous drying medium and said entrained solvent;
   a recycle duct connected directly between said exhaust outlet and said inlet fan means whereby said inlet fan means continuously forces said effluent back through said oven;
   oxidation duct means connected to said recycle duct and said exhaust outlet for receiving a portion of said effluent gases therefrom;
   fan means in said oxidation duct means for forcibly withdrawing said portion of said effluent gases.
from said exhaust outlet; oxidation chamber means connected to said oxidation duct means, and adapted to elevate said portion of said effluent gases to a higher temperature in the presence of sufficient free oxygen to support said oxidation sufficient to oxidize said solvents entrained therein, said oxidation chamber and said recycle duct being so arranged that the temperature of the effluent gases in said recycle duct remains substantially unchanged during recycling; return duct means connected to said chamber for returning a portion of said oxidized gaseous product to said inlet fan means; waste duct means connected to said chamber for conducting the balance of said oxidized gases therefrom and venting the same to atmosphere; air intake means for conducting air to said inlet fan means, and, gas analyser means communicating with said oxidation duct means for continuously analysing said effluent gases from said oven prior to entry into said oxidation chamber whereby to determine the proportion of solvent in said effluent gases.

7. The apparatus as claimed in claim 6 including heat exchanger means connected with said air intake means, and heated by said waste oxidation gases, and adapted to elevate the temperature of said incoming fresh air.

8. The apparatus as claimed in claim 6 wherein said oxidation chamber means, is heated by natural gas burner means, and including temperature sensing means, monitoring the temperature of said oxidation gases after passing through said chamber.