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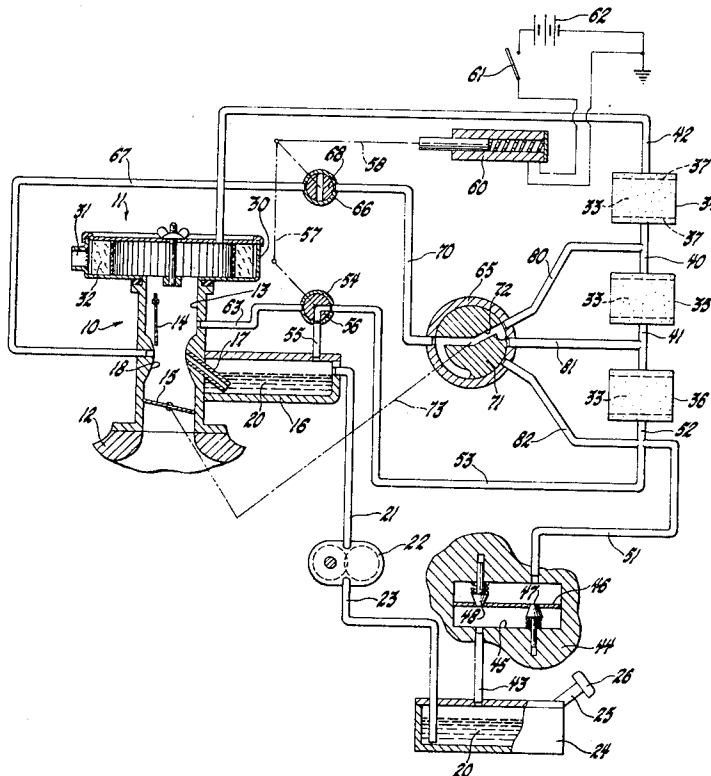
**[54] VAPOR RECOVERY USING A PLURALITY OF
PROGRESSIVELY ABSORBENT BEDS
CONNECTED IN SERIES
10 Claims, 3 Drawing Figs.**

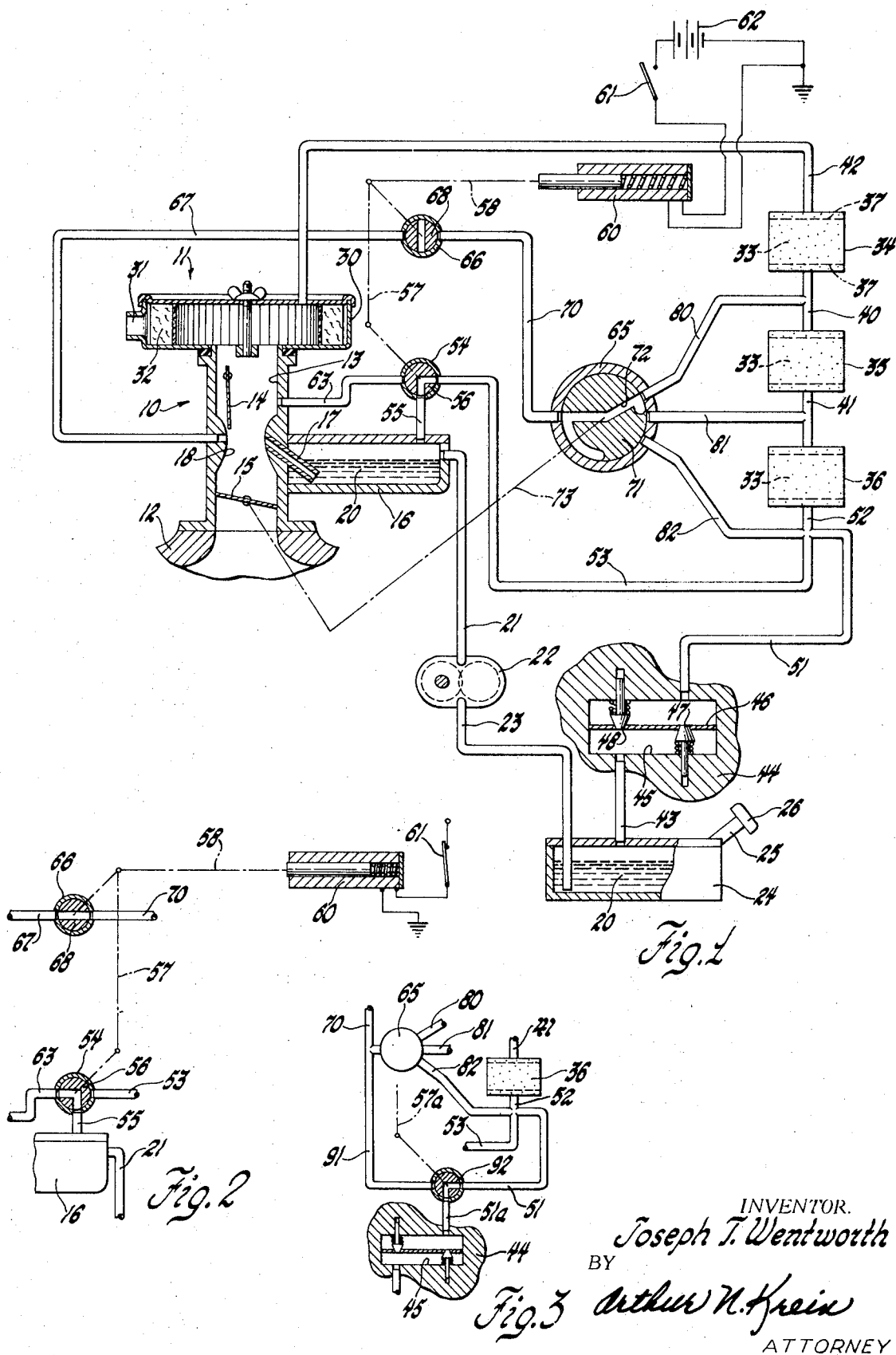
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ABSTRACT: A vapor recovery system for the controlled adsorption and desorption cycling of fuel vapors in an internal combustion engine comprising at least two vapor adsorbent beds connected in series to the fuel bowl of the engine carburetor and to the fuel tank with the adsorbent bed nearest to the source of fuel vapor becoming the most saturated during an adsorption cycle; and, throttle-controlled valve conduits connecting the absorbent beds to the fuel-air induction conduit of the carburetor whereby the least loaded adsorbent bed is purged during low engine loads but, as the throttle is opened to the full open position, all of the adsorbent beds will be purged.





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VAPOR RECOVERY USING A PLURALITY OF PROGRESSIVELY ADSORBENT BEDS CONNECTED IN SERIES

This invention relates to a vapor recovery system for an internal combustion engine and, more particularly, to a system for containing and subsequently consuming hydrocarbon vapors from the fuel system of an internal combustion engine.

It is well known that vapors and gases evolved from internal combustion engines contribute to the present day problem of air pollution. This air pollution problem is due in part to the fact that in the past it has been customary to vent the fuel tank, and at times, the fuel bowl of the carburetor to the atmosphere, thus permitting the emission of hydrocarbon vapor into the atmosphere. These evaporative hydrocarbon emissions may be categorized as follows: carburetor bowl running losses, carburetor hot soak losses, tank running losses, and tank diurnal cycle losses. Carburetor running losses may occur during periods of engine operation due to the warming of the carburetor bowl by the engine. Hot soak is the condition achieved after a warmed-up car is stopped and its engine turned off, bringing about high underhood temperatures to effect the rapid vaporization and loss to the atmosphere of some of the fuel stored in the carburetor fuel bowl. Tank running losses are aggravated by the flow of heated air passing the gasoline tank which is usually mounted in the rear of the vehicle. The tank diurnal cycle is the daily cyclic variation in temperature which causes tank breathing and the resultant loss of vapor even though the vehicle is at rest.

In an effort to reduce the hydrocarbon emissions from the fuel system, various evaporative loss control devices have been proposed whereby, for example, a canister filled with a suitable adsorbent material, such as activated charcoal, is used to adsorb the hydrocarbon vapor when the engine is not in operation. Then, when the engine is operated, means are provided to effect desorption or purging of the vapors from the adsorbent material so that these vapors can then be fed to the combustion chambers of the engine for consumption therein. Also, during engine operation, the running losses from both the tank and carburetor are being consumed as they are generated. This approach has worked successfully to reduce hydrocarbon emissions, but under certain engine operating conditions, the introduction of both the stored and currently generated hydrocarbon vapors for consumption in the engine has either affected engine operation or has caused an increase in the exhaust emission of unburned hydrocarbon.

To help overcome this latter problem, it has been proposed to use a flow control valve to shut off the feedback of the stored hydrocarbon vapors at engine speeds equivalent to roadload speeds below about 30 m.p.h., but this then greatly increases the time required to effect a complete desorption cycle so that complete reactivation of the adsorbent material may not be accomplished under many short intown trips. Under such conditions, it then would be possible after a number of engine-operating cycles of this type to have the adsorbent material become saturated, so that further vapor losses from the fuel could not be adsorbed resulting in the direct venting of hydrocarbon vapors to the atmosphere.

It is, therefore, the principle object of this invention to improve vapor recovery systems whereby desorption of the vapor can be accomplished in a shorter time and with less effect on the air-fuel ratio of an engine than previously known systems.

Another object of this invention is to improve vapor recovery systems for an internal combustion engine to effect a more closely controlled adsorption-desorption cycling whereby to trap hydrocarbon vapors which might otherwise be lost to the atmosphere, and to then feed these hydrocarbon vapors to the engine in such a manner so as to have a minimum effect upon engine operation and minimum increase in emission of unburned hydrocarbon from the exhaust.

These and other objects of the invention are attained by means of a vapor recovery system for an internal combustion engine having at least a first adsorbent bed and a second adsorbent bed, connected in series to each other, with a vent

to atmosphere extending from the first adsorbent bed, this vent line preferably terminating within the induction airflow path in the air cleaner of the carburetor for the engine. When the engine is off, vent lines from the carburetor float bowl and the fuel tank deliver gasoline vapor mixtures to the adsorbent bed, the vent lines being connected directly to the second adsorbent bed with the flow of vapor then being from the second bed to the first bed, whereby the second bed will become more saturated with the vapor than the first bed. Both the first and second adsorbent beds are connected by a throttle-controlled valve conduit means to the fuel-air induction conduit of the engine carburetor whereby induction airflow through the carburetor will cause air to move through either the first bed or the first and second beds, depending on the throttle setting to effect desorption of the vapor from the adsorbent beds. This conduit and the conduit connected to the vent lines from the carburetor fuel bowl are controlled by suitable valves to direct routing of the vapors according to whether or not the engine is in operation.

For a better understanding of the invention, as well as other objects and further features thereof, reference is had to the following detailed description of the invention to be read in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic view of a portion of an engine fuel system incorporating the vapor recovery system of the invention when the engine is off;

FIG. 2 is a fragmentary view of FIG. 1 showing the condition of the vapor recovery system when the engine is in operation; and,

FIG. 3 is a fragmentary view of FIG. 1, but illustrating an alternate arrangement for venting the fuel tank during engine operation.

Referring to FIG. 1, the carburetor 10 and air cleaner assembly 11 are shown mounted on the intake manifold 12 of an engine, not shown. The carburetor 10 has a fuel-air induction conduit 13, a choke valve 14 and throttle valve 15, the latter being connected in a conventional manner to an accelerator pedal, not shown. A carburetor bowl 16 connects through a discharge nozzle 17 with the venturi vent throat portion 18 of the air horn 13 and contains a quantity of liquid fuel 20 to be mixed with air passing the nozzle 17 for discharge into the intake manifold to be consumed in the combustion chambers of the engine. A fuel pump 22, or similar device, supplies fuel through conduit 21 to the carburetor bowl and in turn draws fuel from a fuel tank 24 through a conduit 23, the quantity of fuel being delivered to the carburetor bowl being controlled in the normal manner by a float valve or equivalent means, not shown. Fuel tank 24 is adapted to be filled through a filler pipe 25 normally closed by a nonvented cap 26. The air cleaner assembly 11 mounted on the carburetor, includes the casing 30 with a suitable air inlet 31 thereto and a filter, such as paper filter 32 located in the air path between the inlet 31 and the air horn 13.

As previously described, the effectiveness of the subject vapor recovery system is based upon a controlled adsorption-desorption cycle, the desorption cycle being phased through engine operation as controlled by the carburetor. To accomplish this, the system includes two or more adsorbent beds, connected in series to each other and to the fuel container to be vented.

In the embodiment disclosed, the vapor recovery system is provided with three adsorbent beds, each of the adsorbent ends containing an adsorbent material 33, such as activated charcoal, positioned in canisters 34, 35 and 36. Any suitable means, such as screens 37, may be used to retain the adsorbent material within the canisters and allow aeriform fluid to pass therethrough. Canister 34, containing the first adsorbent bed, is connected by conduit 40 to canister 35 containing the second adsorbent bed, which in turn is connected by conduit 41 to canister 36, containing the third adsorbent bed. Although these canisters can be vented in any suitable manner, for the purposes of obtaining clean air during the desorptive cycle, the vent line 42 connected to canister 34

terminates within the casing of the air cleaner to receive filtered air from the downstream side of the paper filter 32.

The fuel tank 24 is vented to the adsorbent beds by conduit 43 in communication with a valve casing 44 having a chamber 45 therein divided by a valve seat plate 46 into two subchambers in communication with each other by a vacuum relief valve 47 and a pressure release valve 48 schematically represented for descriptive purposes and not described in detail since the specific configuration of these valves forms no part of the subject invention. Conduit 51 then connects this chamber to a conduit 52 in communication with canister 36, the latter also being in communication by conduit 53, valve 54 and conduit 55 to the carburetor bowl 16 for the venting of fuel vapors released from the fuel remaining in the carburetor bowl after engine shutdown. The rotatable valve element 56 of valve 54 is illustrated as being operated through the linkage 57 and 58 by a solenoid 60 controlled by a suitable switch, such as the ignition switch 61, connected to a suitable power source such as battery 62. When the switch 61 is open and the engine is not in operation, the valve element 56 is in the position shown in FIG. 1, with conduits 53 and 55 in communication with each other. During engine operation, as shown in FIG. 2, the vapors from the carburetor bowl are vented by a conduit 63 directly to the carburetor and then to the engine for consumption therein, the conduit 63 being connectable by the valve element 56 to vent conduit 55 during engine operation, the opposite end of conduit 63 being in communication with the air horn of the carburetor.

To effect controlled desorption in direct relation to the operating conditions of the engine, the flow of air through the canisters and then to the carburetor is controlled by a distributor valve 65 and valve 66. Vent line 67 in communication with the venturi portion 18 of the fuel-air induction conduit is connected to valve 66, schematically represented here for descriptive purposes, having rotatable valve element 68, which is also operated through the linkage 58 by solenoid 60, previously described. Of course, other suitable means may be used to control valves 54 and 66, such as a diaphragm activated by engine oil pressure. When the switch 61 is open and the solenoid 60 deenergized the rotatable valve element 68 is in the position shown in FIG. 1, in which it blocks the flow of air or vapor in line 67. When the ignition switch 61 is closed as shown in FIG. 2, the rotatable valve element 68 connects the vent line 67 with conduit 70 which in turn is connected to the outlet side of distributor valve 65. As shown schematically, distributor valve 65 has a rotatable valve element 71 with a passage 72 therein for selective connection to conduits 80, 81 and 82 in communication with conduits 40, 41 and 42, respectively. The rotatable valve element 71 is illustrated as being operated through linkage 73 herein shown as coupled to the throttle valve 15, so that the displacement of the rotary valve element 71 is directly related to the setting of the throttle valve, as described hereinafter, so that the route of purging air through the various adsorbent beds can be controlled by the distributor valve. Furthermore, by having vent line 67 connected to the carburetor venturi portion 18, the airflow rate through the canisters increases in proportion with engine-air consumption.

When the engine is not in operation, that is, when switch 61 is in the open position, the various valve elements are in the position shown in FIG. 1. In this arrangement, fuel vapors emitted from the fuel bowl 16 via conduit 55 and from the fuel tank 24 via conduit 43 are conveyed successively through canisters 36, 35 and then 34, the latter being vented to the atmosphere via conduit 42. However, assuming that the adsorbent material 33 in these canisters initially contains no adsorbed hydrocarbon vapors, then the vapors coming from the fuel bowl and the fuel tank will first enter canister 36 with most of the fuel vapor being adsorbed therein. Of course, as the adsorbent material in canister 36 becomes saturated, more of the hydrocarbon vapors will pass into canister 35 whereby the majority of hydrocarbon vapors will be adsorbed therein,

and again, as this adsorbent bed becomes saturated, the hydrocarbon vapors will then pass into canister 34 for adsorption therein. Thus, in essence, the adsorbent material in canister 36 will be the first to be saturated, after which the material in canister 35 will become saturated, and finally, canister 34 will become the least saturated. Of course, it is assumed that the canisters 34, 35 and 36 will contain sufficient adsorbent material so that under normal conditions, all of the hydrocarbon vapors given off from the fuel bowl and fuel tank will be adsorbed so that no hydrocarbon vapors will be emitted to the atmosphere via vent line 42, with the bed in canister 36 being the most saturated with vapor while the bed in canister 34 would be the least saturated.

In this regard, although a sufficient quantity of adsorbent material is contained in the system, each of the adsorbent beds need not be of equal size, as shown, since design consideration may necessitate different sized canisters for adequate location under the hood in relation to other equipment and, in addition, it is also realized that pore size distribution of the adsorbent may vary from one canister to another. For example, canister 36 may contain adsorbent material having a larger average pore size to retain the larger molecules of vapor while passing more of the smaller molecules, such as C_4 and C_3 hydrocarbons, to beds 35 and 34. Beds 35 and 34 may contain adsorbent material having somewhat smaller average pore size which is well suited for the retention of C_4 and C_3 hydrocarbons but which would hold heavier molecules too tenaciously for easy desorption, as is well known in the art.

When the engine is in operation, that is, when switch 61 is closed, the valve elements 54 and 66 are moved to the positions shown in FIG. 2. In this arrangement, the carburetor bowl 16 is now vented directly to the air horn of the carburetor via conduit 55 and 63. In addition, rotatable valve element 68 of valve 66 has now placed vent line 67 and conduit 70 in communication with each other. With the engine in operation at idle, the throttle valve 15 would be in the position shown whereby, through the linkage 73, the rotary valve element 71 of distributor valve 65 would then be in the position shown in FIG. 1, so that the passage 72 therein, effects a connection between conduit 70 and conduit 80 to permit air to flow only through canister 34. At idle, the engine airflow is at its lowest and idle air-fuel ratio is most sensitive to the amount of air or vapor admitted through conduit 67. In the arrangement disclosed, however, the total flow through conduit 67 is also at its lowest, being proportional to engine airflow. Further, the possibility of drawing a high concentration of vapor is reduced by purging only a lightly loaded portion of the total adsorbent that is, the adsorbent bed in canister 34. As engine speed is increased, the throttle valve 15 is opened further and as the purge airflow rate increases, the rotatable valve element 71 of distributor valve 65 is moved to connected passage 72 therein with conduit 81 so that the purge air flows through both canisters 34 and 35 and, at full throttle, passage 72 would be in communication with conduit 82, with purge air then flowing through all of the canisters. Thus, the distributor valve is used to control the flow of purge air to more saturated adsorbent beds as the engine speed and purge airflow rate is increased, where engine air-fuel ratio is less sensitive to the added vapor. With this system, better use is made of the purge air which the engine can tolerate. Purging progresses at the full range of engine operation, which shortens the length of time required to prepare the adsorbent material for subsequent loading. However, the flow of purge air and also the concentration of vapor in the purge stream are continuously modulated to minimize either excessive leaning or richening of the overall air-fuel mixture entering the engine intake.

As previously described, the vapor outlet from the fuel tank 24 is provided with both a vacuum relief valve 47 and a pressure relief valve 48. As vapor pressure rises in the fuel tank, the pressure relief valve opens to allow vapor to flow to the adsorbent beds in canister 36, or if the engine is operating at full throttle, the vapor from the fuel tank is drawn directly

into the carburetor. Because a pressure relief valve is sensitive to the differential pressures on opposite sides of the valve element, the vapor pressure in the fuel tank will probably be relieved in spurts during periodic accelerations. This follows from the fact that the pressure depression at the venturi throat portion 18 increases with throttle opening, and that by operation of the distributor valve, purge air is progressively drawn through more adsorbent material. Both of these factors tend to increase the depression or partial vacuum on the downstream side, in terms of the direction of flow of vapor from the tank, of the pressure relief valve. Assuming that the engine is a vehicle engine and that pressure in the fuel tank will build up uniformly while the vehicle is being driven in normal traffic situations including periodic accelerations, most of the vapor from the fuel tank will be released directly into the carburetor and will not be deposited on the adsorbent material. Since a majority of fuel tank vapors are evolved during driving periods, the system disclosed is helpful in keeping the required size of the total adsorbent bed material to a minimum.

In some vehicles, the engine power-vehicle weight ratio may be large enough so that the throttle is seldom opened enough to cause conduit 70 to be directly connected to conduit 82 by means of valve 65. In such cases, the linkage 73 between throttle valve 15 and the valve element 71 of distributor valve 65 can be modified or the configuration of passage 72 in the valve element 71 can be changed to effect a connection between conduit 70 and conduit 82 at a throttle setting less than full throttle, but at the higher engine speeds normal for the particular vehicle, to insure the complete purging of canister 36 and more frequent direct venting of vapor from the fuel tank to the fuel-air induction conduit of the carburetor during engine operation. Alternately, to effect direct venting of vapor from the fuel tank to the fuel-air induction conduit during engine operation but, independent of the speed thereof, a valved conduit can be used to bypass the distributor valve as illustrated in the embodiment of FIG. 3. As shown schematically, the conduit 51 and 91 are selectively coupled by valve 92 to conduit 512 in communication with chamber 45, conduit 91 being connected to conduit 70. Valve 92, similar to valve 54, is operable by linkages 57a and 58 and routes fuel tank vapors to the adsorbent beds when the switch 61 is open, as before. When switch 61 is closed, however, this added valve connects the outlet from chamber 45 directly to conduit 70. In operation, the venting of the tank will be similar to that already described except that it no longer will be necessary to open the throttle fully in order to pass tank vapors directly to the engine. Vapor passage can occur at any throttle opening, depending on the differential pressure across valve 48. Of course, the tank will still vent in spurts during periods of acceleration because of the factors controlling the depression on the downstream side of the pressure relief valve 48, as previously described.

I claim:

1. A method for the recovery of fuel vapors from the fuel bowl of the carburetor and fuel tank of an internal combustion engine comprising the steps of: sequentially loading a plurality of beds of adsorbent material with fuel vapors while the engine is not in operation; sequentially unloading said beds with purge aeriform fluid in the reverse order of loading during engine operation, and conducting the thus purged vapors to the fuel-air induction conduit of said carburetor.

2. A method for the recovery of fuel vapors according to claim 1 including the steps of venting fuel vapors from said fuel bowl directly to the fuel-air induction conduit of said carburetor during engine operation and venting fuel vapors from said fuel tank directly to the fuel-air induction conduit of said carburetor during periods of high-speed engine operation.

3. A method of recovering fuel vapor from an engine fuel system, said method comprising the steps of: sequentially storing fuel vapor from the engine fuel system in a plurality of adsorbent beds when the engine is not operating, releasing the stored fuel vapor during engine operation by supplying

aeriform fluid to the stored fuel vapor proportionate to the air flow rate into the engine air intake with the fuel vapor release being carried out in the reverse order of sequential fuel vapor storage with the fuel vapor release responsive to air flow progressing from the least loaded adsorbent beds during low air flow to the more loaded adsorbent beds as the air flow increases, and conducting the released vapor to the engine air intake during engine operation and burning the released vapor therein.

4. A fuel vapor recovery system for an internal combustion engine having a fuel reservoir and a carburetor containing a venturi, a throttle valve restricted throat and a fuel bowl, said system comprising a plurality of fuel vapor storage means, conduit means connecting said fuel vapor storage means with said fuel reservoir and said fuel bowl when the engine is not operating to load said fuel vapor storage means in a fixed vapor storage sequence, vent means connecting said fuel vapor storage means to a source of aeriform fluid to release stored vapor, valved conduit means including distributor valve means connecting said vapor storage means to said venturi of said carburetor when the engine is operating and, linkage means connecting said distributor valve to said throttle valve whereby said distributor valve controls the release of vapor from said fuel vapor storage means in the reverse order of said fixed vapor storage sequence as a function of the throttle valve setting.

5. A fuel vapor recovery system according to claim 4 wherein said plurality of fuel vapor storage means comprises at least a first canister and a second canister each containing a quantity of adsorbent material, said conduit means including a conduit connecting said first canister in series with said second canister, with said first canister being connected to said vent means and said second canister positioned to first receive fuel vapor from said fuel reservoir and said fuel bowl when the engine is not in operation, said distributor valve being connected to said throttle valve to control the flow of aeriform fluid through said first canister when the engine is operating at idle and to effect the flow of aeriform fluid through said first canister and said second canister when said throttle valve is opened during higher speed engine operation.

6. A fuel vapor recovery system according to claim 4 wherein said conduit means includes a pressure relief valve and a vacuum relief valve positioned between said fuel reservoir and said plurality of fuel vapor storage means and wherein said valved conduit means includes a first valve to prevent the flow of fuel vapor to said venturi when the engine is not in operation and a second valve to convey vapor from said fuel bowl to the fuel-air induction conduit of said carburetor when the engine is in operation.

7. A fuel vapor recovery system for an internal combustion engine having a fuel reservoir and a carburetor with a venturi and throttle valve restricted fuel-air induction conduit and a fuel well, said system comprising a plurality of vapor adsorption bed means, conduit means connecting said bed means in series with respect to each other and at one end to a source of aeriform fluid and at the other end to said fuel reservoir, first valve-controlled conduit means for selectively coupling said fuel well to said conduit means between said fuel reservoir and said adsorption bed means when the engine is not in operation and to said fuel-air induction conduit when the engine is in operation and, second valve-controlled conduit means including a distributor valve operatively connected to said throttle valve for selectively coupling said adsorption bed means via said conduit means to said venturi in accordance with the setting of said throttle valve when the engine is in operation and to block the flow of vapor from said adsorption bed means and said fuel reservoir to said venturi when the engine is not in operation.

8. A fuel vapor recovery system according to claim 7 wherein said plurality of adsorption bed means includes a first bed means, a second bed means and a third bed means, said conduit means connecting said first bed means at one end to a source of aeriform fluid and, at the other end, to said second

bed means, said second bed means to said third bed means and said third bed means to said fuel reservoir, said second valve-controlled conduit means including a first conduit connecting said distributor valve to said conduit means between said first bed means and said second bed means, a second conduit connecting said distributor valve to said conduit means between said second bed means and said third bed means and a third conduit connecting said distributor valve to said conduit means between said third bed means and said fuel reservoir.

9. A fuel vapor recovery system according to claim 8 wherein said conduit means includes a pressure relief valve and a vacuum relief valve positioned between said fuel

reservoir and said third conduit.

10. A fuel vapor recovery system according to claim 9 further including third valve-controlled conduit means connected to said conduit means between said vapor adsorption bed means and said fuel reservoir and to said second valve-controlled conduit means between said distributor valve and said venturi, said third valve-controlled conduit means including a control valve means to route vapor from said fuel reservoir to said vapor adsorption bed means when the engine is not in operation and to route vapor from said fuel reservoir to said venturi when the engine is in operation bypassing said vapor adsorption bed means.

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