United States Patent

[11] **3,566,800**

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[54] **TRANSPORTATION SYSTEM**
10 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **104/138**
[51] **Int. Cl.** **B61b 13/10**
[50] **Field of Search** ..... 104/23, 23(FS), 134—137; 104/138

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ABSTRACT: A novel transportation system is described including a payload carrying vehicle, and a close fitting tube through which the vehicle travels. Aerodynamic drag on the vehicle is substantially eliminated by effecting, thermodynamically, a phase change in the tube medium in advance of the vehicle which is reversible to the rear of the vehicle.

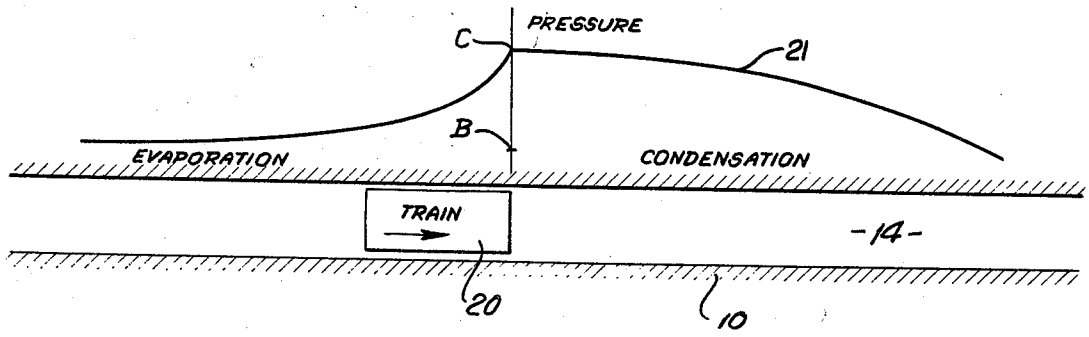


FIG. 1.

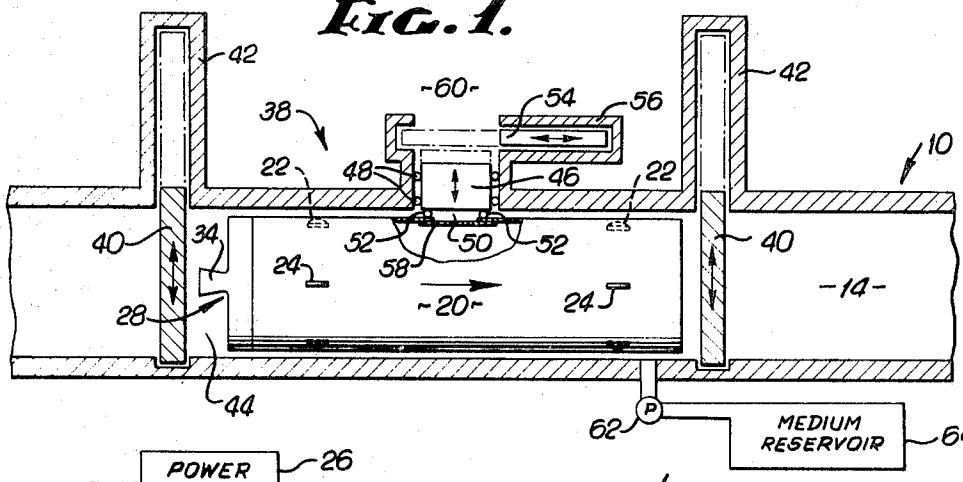


FIG. 2.

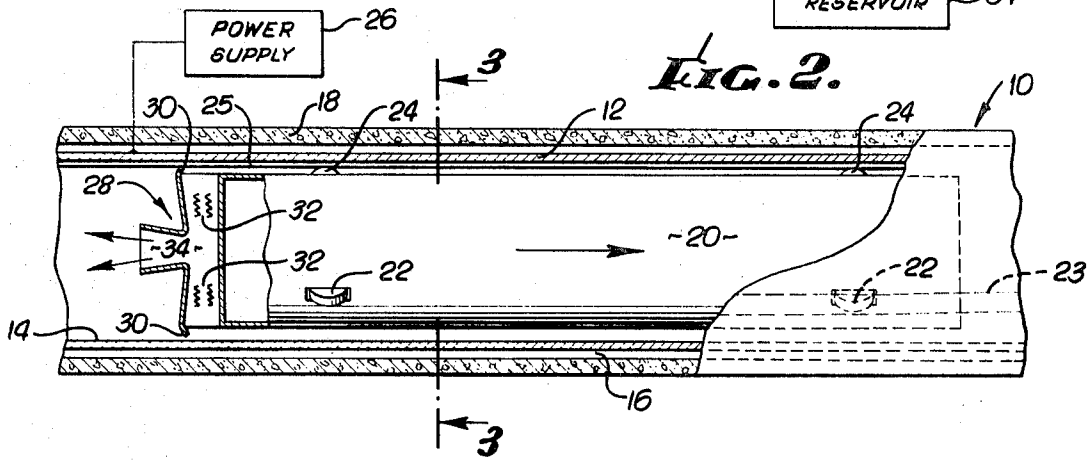


FIG. 4.

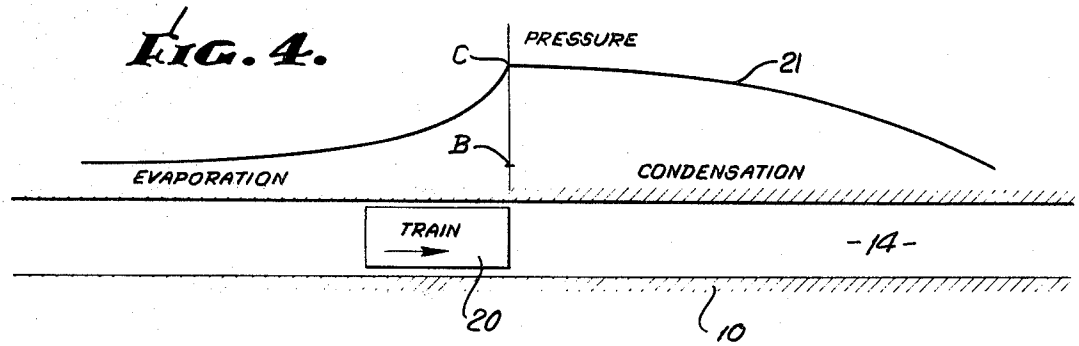
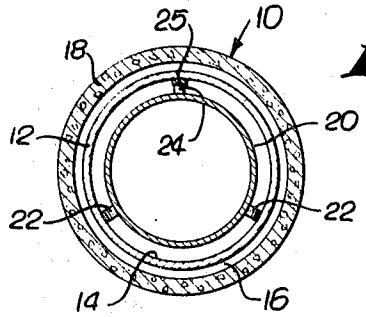


FIG. 3.



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TRANSPORTATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention has to do with ground transportation and has particular reference to method and apparatus for the high speed movement of payloads consisting of passengers and/or freight, from point to point in a ground related system without substantial aerodynamic drag by virtue of a localized phase change produced in the medium through which the payload vehicle travels.

Transportation is concerned with the physical movement of people and freight from place to place. Efforts at improving the speed, economy, comfort and sea safety of transportation have in the last few decades been concentrated largely on the airplane, the auto and the truck. As a consequence, these modes of transportation have advanced to the point where they are environmentally rather than technologically limited, particularly in terms of speed. Not sharing to any great degree in the advances in transportation technology have been fixed path ground systems, primarily railroads. Sporadic efforts to introduce new concepts, e.g. the monorail, have in the main failed to attack the basic problem—speed limitation. There are manifold benefits inherent in fixed path ground systems, including central location of terminals. This can save hours on a trip relative to use of a remotely located airport. In addition fixed path systems offer very high efficiencies in terms of payload weight carried per unit of fuel consumed as compared with the auto and the truck. This efficiency augers a reduction in air pollution, or its elimination where electric power is employed. Further fixed path systems provide a high safety factor, particularly for the speeds involved, since most operation can be automatic.

2. Description of the Prior Art

To recapture their rightful place in the transportation scheme, fixed path systems must be faster. While effects such as mechanical drag, e.g. friction and vibration are presently barriers to very high speed ground transportation over fixed paths, technology is available to overcome these limitations. Aerodynamic drag, which is the resistance offered to a vehicle passing through a gaseous medium, is one of the limiting technology barriers when speeds well over 100 miles per hour are considered.

The aerodynamic drag is made up of pressure drag and frictional drag, although generally it can be related to speed through a single coefficient which is empirically determined. Thus

$$D_a = \beta\beta^2 = C_D A \tfrac{1}{2}\rho V^2$$

wherein D_a = aerodynamic drag, β an empirical constant, V velocity and A the cross-sectional area of the vehicle and in which the density ρ of the medium through which the vehicle moves appears to the first power. While it may appear that aerodynamic drag can be reduced in direct proportion to the gas density, which suggests use of an evacuated tube, the drag coefficient C_D actually increases significantly for a vehicle in an enclosed tube over its value for the free air case. Whereas a modern streamlined train with articulated cars shows an aerodynamic drag coefficient C_D of only about 0.2, in an enclosed tube C_D can be more than an order of magnitude higher. Studies of the gasdynamic aspects of an enclosed hypersonic test track show a drag coefficient of 3.5 for a close fitting piston moving at Mach 1, and increasing with decreasing Mach number, being about 5 at Mach 0.5. Studies of the dynamics of a tube vehicle show experimental drag coefficient values as high as 6 for a closed-ended tube whose diameter is 1.25 times that of the vehicle diameter. Even for a diameter ratio of 2 (a very loose fitting train in the tube), the drag coefficient is still about 1. Thus, any advantage that could be gained by reducing gas density is cancelled by the increase in the drag coefficient, unless the gas density can be reduced to about two orders of magnitude under that in free air.

The reason for the much higher drag coefficient in a tube compared to that in free air is, of course, caused by the pressure buildup in a tube. In the present invention a medium phase change is employed so that the situation is much like that in free air, because the pressure ahead of the vehicle cannot build up, due to the phase change. Full advantage can, therefore, be taken of the gas medium density reduction in a tube to achieve truly low aerodynamic drag.

Some have proposed removing the medium locally in front of the vehicle as it is displaced by the advancement of the vehicle through a series of electrically or pneumatically operated valves which would bypass the displaced air or other ambient medium relative to the moving vehicle and replace it in the naturally occurring reduced pressure zone to the rear of the vehicle. This approach is obviously fraught with mechanical complexities prohibitive of success when systems hundreds of miles long are considered.

The problem of aerodynamic drag can be reduced to two aspects: the first is medium displacement; as the vehicle advances, the medium is pushed ahead of it creating a resisting back pressure insofar as medium displacement rate is insufficient, i.e. less than the vehicle advancement rate. The second aspect is the frictional drag of bypass or flow occurring at the surface of the vehicle, where the medium passes the vehicle. As pointed out above, in a tube, both displacement and bypass drag problems are exacerbated by the confining proximity to the vehicle of the wall around the displaced medium. Solutions to this problem, heretofore proposed, have sought by mechanical means of great complexity to remove the medium either locally or totally from the tube.

SUMMARY OF THE INVENTION

According to the present invention, a solution to drag is provided in terms of thermodynamic relations rather than mechanical expedients; in proper selection of the medium rather than its elimination; and in a physical change in the medium rather than a displacement thereof. The present invention obviates the need for continuous high vacuum pumping since presence of a medium is tolerable within the tube. In addition, in the invention, flow friction is substantially eliminated so that bypass drag is negligible. Thus, in accordance with the present invention, displacement resistance and bypass resistance are overcome; aerodynamic drag is thus removed as the limiting technological barrier to ultrahigh speed fixed path transportation systems.

The invention is predicated on the major concept, among others, of effecting a phase change in the medium through which the vehicle moves, locally in advance of the vehicle, e.g. effecting condensation of an ambient vapor to remove medium from in front of the vehicle thereby to reduce drag attributable to too slow medium displacement; and maintaining the medium in its physically changed state as the vehicle passes, e.g. as condensate on the walls defining the vehicular path, to accomplish bypass of the medium without the drag effect of surface flow. The inherent partial vacuum developed behind the moving vehicle locally shifts the system equilibrium sufficiently that the changed medium is returned to its normal state, e.g. the condensate is revaporized and ready for recondensation on the advance of the next vehicle.

Utilizing this principle of operation, the invention provides a transportation system with a unique method of passing an ambient medium enclosed within a space defined by a wall around a vehicle passing therethrough, which method includes condensing the medium locally in advance of the vehicle against the wall, maintaining the medium in the condensed phase locally adjacent the vehicle during relative movement of the medium and vehicle and restoring the medium to its normally gaseous ambient condition to the rear of the vehicle.

The invention is concerned with both a method and an apparatus for fixed path transportation. More particularly, the invention provides a method of operating a vehicle in a tube or other elongated confined space containing an ambient medi-

um including advancing the vehicle within the medium in the space, and effecting a phase change in the medium locally in advance of the vehicle to reduce aerodynamic drag thereon as by confining the medium within a boundary defining a path of vehicle advancement and pressurizing the medium by advancing the vehicle thereagainst. Vapor media are phase changeable to liquid by such pressurization; revaporization is inhibited in advance of the vehicle by removing phase change produced heat from the generative locus thereof, i.e. the point of phase change. Revaporization or other reverse phase change such as sublimation may be effected to the rear of the vehicle by the pressure reduction caused by movements of the train and/or by heat input to the condensed phase medium to shift the equilibrium parameters within the space to a vapor supporting condition.

Apparatus is provided for carrying out the method of vehicular movement including a closed guideway having a wall defining and enclosing a vehicular path and, confined within the guideway, and along the path, a gaseous medium locally phase changeable by local subjection to an incremental increase in pressure, e.g. a vapor medium condensable to the liquid phase by a pressurizing means within the guideway. The wall portions adjacent medium phase change locations are maintained in an essentially isothermal condition, e.g. by being in heat conductive relation with an essentially constant temperature body such as the ground or water in great quantities. The guideway is sized to accommodate a propellable vehicle having propelling means and located to advance along the guideway path and which may pressurize the medium locally ahead of its advance. Bearing surfaces may be provided along said path to guide the vehicle and means can be provided on the vehicle to engage these bearing surfaces in guiding relation. The vehicle may also include jet structure to receive condensed medium and to expel the same for propulsive effect.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more particularly described as to a specific embodiment thereof in conjunction with the attached drawings in which:

FIG. 1 is a generally schematic view from above of the apparatus of the invention including a vehicle located at a payload receiving and discharging lock;

FIG. 2 is a view in elevation of the apparatus also showing a vehicle and its propulsion system;

FIG. 3 is a view along lines 3–3 in FIG. 2; and

FIG. 4 is a schematic representation of the apparatus showing a pressure profile relative to the vehicle moving through the apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Operation of the present invention may be considered to be predicated on:

2. the exponential dependence of vapor pressure on temperature, and
2. the capacity of the tube wall to act as an isothermal infinite heat sink.

The equilibrium between the vapor and condensed (either liquid or solid) phases of a substance is governed by the Clapeyron-Clausius equation

$$\frac{dp}{dT}=\frac{L}{T\Delta V}$$

in which p is the vapor pressure, T the temperature, L the latent heat of transformation and ΔV the change in volume during transformation. A practical integrated form of the equation is

$$\log_{10} p_{mm}=-\frac{a}{T}+b \log_{10} T-cT+ \ldots$$

in which p is measured in millimeters of mercury and T in degrees Kelvin absolute, and the constants a, b, c, etc. are the so-called virial coefficients which are established empirically for various substances. From this relationship it is seen that a temperature change of only a few degrees is required to change the vapor pressure by tens of millimeters. The Clapeyron-Clausius equation also dictates that the equilibrium between the vapor and condensed phases of a substance is such that

1. if temperature is held constant and pressure is raised in the vapor the vapor will condense so as to reduce the pressure back to that appropriate to the temperature; and that
2. if the condensate temperature is raised some of the condensate will evaporate so as to raise the pressure of the vapor to that level which is appropriate to the increased temperature.

These phase equilibrium conditions are readily seen to be ideally suited for the operation of a vehicle in a closed tube.

Assuming a long closed tube filled with a medium which at the temperature of the tube exists in equilibrium of two phases with its vapor filling the tube at some pressure p_o and its liquid or solid phase adhering to the tube wall at some temperature T_o, the pressure p_o is then the vapor pressure corresponding to the temperature T_o. The medium substance can be selected such that this pressure p_o is quite low, e.g. on the order of 5 mm. (less than one-hundredth of an atmosphere). If now a close-fitting vehicle is moved inside the tube, the advance, analogously to a piston, would tend to compress the vapor in the part of the tube ahead of the vehicle. But the phase equilibrium condition will cause the vapor to condense onto the tube wall. Assuming the latent heat of condensation can be removed from the wall, a transient situation will develop in which there is a slight increase in the pressure (to p_l) and temperature (to T_l) of the vapor ahead of the vehicle with the increase rapidly decaying to the equilibrium value far ahead of the vehicle. There is thus no permanent increase in the pressure inside the tube resulting from the vehicle advance. The pumping action which removes the vapor displaced by the "piston" is accomplished, not with mechanical pumps, but by condensation onto a surface.

As indicated, the present invention requires a closed space or guideway having a wall defining and enclosing a vehicular path. Accordingly, a tube is provided extending between the terminals of the transportation system. The construction of the tube is largely dictated by environmental considerations but will in all cases be of an inside diameter adequate to surround, preferably closely, the vehicle used for transport. A typical tube for passenger service might be 11 feet in inside diameter for a vehicle 10 feet in diameter. For freight movement, considerably smaller tubes, e.g. 2 to 4 feet in diameter may be used. Provision for supporting the vehicle within the tube may be provided consistent with the vehicle suspension system hereinafter described, e.g. rails or other bearing surfaces affording minimum possible friction may be provided along the tube interior for engaging the wheels or skids, if any, on the vehicle in guiding relation. The materials of tube construction can be any of the well-known architectural materials such as steel or concrete, or the newer materials such as reinforced plastics formable into a tubular configuration and joinable with a fluid tightness enabling control of the environment within the tube. Preformed cylindrical sections having bell and spigot ends, similar to water pipe sections now in use, are quite feasible for the basic tube, lined either interiorly or exteriorly, if need be for internal environment control. The cross-sectional shape of the tube is not critical and can be square, rectangular, round or otherwise shaped, e.g. to conform to the vehicle profile. For purposes to appear, it may be desirable to provide one or more coaxial tubes around the basic tube.

A further requirement of the tube wall material is ability to conduct heat out of the tube interior. Certain materials such as metals including steels and aluminum will of course conduct heat well; other materials, inherently less heat conductive, such as concrete can be internally modified, e.g. by ducting or coring to improve heat translation capabilities.

Obviously much of the technology developed in laying transcontinental pipelines is applicable to construction of the tube here considered. In fact, many existing pipe lines can be adapted for freight forwarding using this invention.

Because of the wide variety of suitable materials for tube construction, the external environment of the tube is not narrowly restricted. Thus, the tube may be above the surface, upon the surface, or subterranean or under water or have portions along its length in various of these external environments, i.e. air, earth or ground and water. The selection of tube material will of course be determined by the external environment with due regard for corrosion, hydrolysis potential and pressure exposure. Use can be made of the tube external environment to facilitate heat removal from within the tube. Thus a tube buried in a trench below the local frost line will be in intimate contact with an essentially constant temperature body, the ground, and heat generated within the tube, e.g. by condensation of the medium therein, and transmitted through the tube wall will be dissipated into the ground without a measurable increase in ground temperature, the ground acting as an infinite heat sink. Water bodies similarly will be effective as a heat sink in underwater installations of the tube. In certain embodiments, to be described in conjunction with the drawings, transient water may be provided around the interior tube wall for heat transfer and other purposes.

Illustratively, the tube may be set in a trench, at a depth of 20 feet or so, and surrounded with earth. Along the Northeast Corridor of the United States, i.e. the area extending from New York to Boston, the subsurface ground is comprised mainly of post-precambrian granite which has heat flow properties quite adequate to carry away heat generated by operation of the system. For example, the thermal conductivity of this material varies between about 3×10^{-3} and 7×10^{-3} cal./cm. deg. ° C. which is higher than most common liquids; water $= 1.4 \times 10^{-3}$, alcohol $= 4.2 \times 10^{-4}$ and Freon 2.0×10^{-4} and the thermal diffusivity of earth is also higher than that of most liquids.

As indicated above, the tube contains a medium responsive to pressure and/or heat variations to change from a gaseous to a solid or liquid phase and to reverse the change with opposite variations. Numerous materials will, of course, undergo phase changes under these conditions. In selecting a medium these factors for each candidate material are borne in mind: the temperature-vapor pressure relation, the latent heat of phase change, the specific heats of the vapor and condensed phases, the thermal conductivities of these phases, vapor and condensed phase viscosities and densities, as well as the chemical stability, reactivity and toxicity of the medium. For most installations of the system, a medium is selected which is in the condensed phase with low vapor pressure at the constant subterranean earth temperature, i.e. about 68° F. Only small quantities of the medium need be employed so that the amount of condensed phase in the tube will be small per unit of surface area therein; thus viscosity and surface tension properties of the condensed medium will insure adherence to the wall of the medium in a thin film. Of course, materials passing directly from a gaseous to a solid phase, e.g. carbon dioxide will be suitable, but many materials natural and synthetic, inorganic and organic which exist in three phases are practicable media. The most abundant and in many respects optimum material is water itself. Other materials which may be mentioned are synthetic organic substances, including compounds and polymers, tailored to meet the above set out criteria. Principally these will be halogenated hydrocarbons, e.g. fluorinated and chlorinated hydrocarbons and their polymers having molecular weights of e.g. 15 to 400 to provide a condensed phase with low vapor pressure at expected ambient temperatures, generally 50° to 75° F. such as a Freon, e.g. tetrachlorodifluoroethane. Also suitable are chemically analogous materials such as silicone compounds, including polymers, again of molecular weights to have the desired vapor pressure characteristic, i.e. 15 to 400.

The required vapor pressure characteristic in the medium enables the tube to be filled with a vapor or other gaseous form of the medium and locally evacuated of the medium by a decrease in temperature or an increase in pressure at the medium location. Since suitable materials have been described as having a low vapor pressure, which generally is of the order of 0.2 to 40 mm. Hg. at the 68° F. wall condition assumed, above a slight pressure increment will cause condensation or removal of the vapor. The heat of condensation, which can be considerable, is passed into the wall and diffused into the surrounding matrix of earth or water. Therefore, materials not readily condensed, i.e. those having a high vapor pressure at operating temperatures, e.g. normally gaseous materials, unsuitable unless sufficient pressure can be developed to condense these materials by vehicle movement through a tube. Ordinarily, common atmospheric gases will be removed from the tube. Thus nitrogen and oxygen, particularly, are first evacuated from the tube and the selected medium is placed therein with the vapor and condensed phase practically at equilibrium at the ambient temperature. Gases generated by the vehicle, if any, are withdrawn from the tube if present in amounts sufficient to render the medium nonphase changeable by advance of the vehicle therethrough.

It will be noted that once evacuated and filled with a vaporous medium, the tube is self-operating and mechanical pumps are not needed to continuously evacuate the tube or move medium from place to place, since medium "movement" is thermodynamic rather than mechanical.

The vehicle for carrying payloads through the tube can be any conveyance having a conventional, e.g. spring and wheel or skid or unconventional, e.g. fluid suspension system or electromagnetic suspension. The interior of the vehicle is tailored to the intended payload; the exterior should be resistant to the medium, but otherwise is noncritical. Lightness of weight is desirable, suggesting the use of aluminum or magnesium metals or any of various reinforced plastics. The exterior contour is not critical, but desirably fairly closely conforms to the tube cross section to better develop a condensing pressure rise in advance of the vehicle. Of course, multiple car vehicles can be employed. A conventional rail and track guidance and suspension arrangement at moderately high speed is acceptable from a rolling friction drag point of view and is recommended. At extremely high speeds, electromagnetic or gaseous suspension is considered desirable.

The vehicle is provided with propelling means compatible with the suspension system. For a rail and track arrangement, a conventional electric motor mounted on the vehicle to drive the wheels and drawing power from a "third rail" in the tube is most satisfactory. Other propelling means can be employed in replacement of or supplementary to electric power. For example, and particularly for all-freight systems, boosters located strategically can provide propulsive force so that no onboard power is required. These boosters can take the form of pressure impulses, e.g. high pressure steam injections behind the vehicle for acceleration (or conversely before the vehicle for deceleration) particularly where the medium being used is water. Other pressurized media can of course be used. Alternatively, the boosting of vehicle speed may be mechanical as with catapults or chain drives.

It is also feasible to use the medium within the tube as a source of propulsive energy. Specifically the pressure behind the vehicle can be increased by expanding the vapor to the rear of the vehicle by increasing the temperature thereof. For this purpose heaters can be deployed along the tube wall or at the rear of the vehicle to radiate heat to the tube wall and working medium in passing the condensate thereon, which vaporizes the condensate and generates pressure behind the vehicle. This propulsive force can be used alone or in conjunction it with more conventional powering systems. Propulsion by combustion of fossil fuels should be avoided unless the exhausts, which are generally incompressible can be readily removed from the tube.

Turning now to the drawings, and particularly FIGS. **1—3** a preferred embodiment of the invention is shown including a tube **10** having a cylindrical metal wall **12** defining a vehicle

path **14**. Concentric with the wall is a water filled annulus **16** for purposes to be explained and surrounding the annulus a wall **18** of aggregate and cement is provided. The assembly can be above, level with or below ground or a water body. An annular water layer around the inner wall **12** keeps the interior surface in an isothermal condition and enables positioning of the tube above or level with the ground or underneath, or in any combination of these positions. The annular space **16** can also serve as a conduit for the water therein and may function, therefore, as an aqueduct. In addition, the annular space may function as a reservoir for the medium within the space.

The vehicle path within interior of the tube **10** is evacuated of normally gaseous materials such as oxygen, nitrogen, argon, carbon dioxide and nitrogen oxides and filled with one of the herein-described phase changeable media, e.g. a water/water vapor mixture. The tube is brought to a pressure of between 0.2 and 0.40 mm Hg. (calculated at 0° C.). It will be noted that the absence of continual mechanical pumping and concomitant numerous mechanical seal points eases pressure maintenance problems. The provision of a water filled annulus **16** about the tube seals the tube from gas incursion, assuring that leakage, if any, will be of water, and such provision is thus desirable where water is the selected medium. There is thus provided an apparatus for vehicular movement including closed guideway having a wall **12** defining and enclosing a vehicular path **14** and having, confined within the guideway and along the path a gaseous medium locally phase changeable by local subjection to incremental increase in pressure. The medium can be water at a pressure of about 14 mm. Hg. at 68° F. and therefore in substantial equilibrium with its vapor.

Means to pressurize the water medium to the liquid phase are provided. Typically the vehicle **20** serves as the pressurizing means. Closely fitted in the path **14**, the advance of the vehicle along the guideway path is similar to a piston within a cylinder in that the medium is compressed, i.e. subjected to a compacting increase in pressure.

Referring to FIG. **4**, the normal pressure profile within the tube and about the vehicle is depicted. It is seen in reference to curve **21** that immediately ahead of the vehicle, the pressure along the path **14** is the greatest with a gradually declining value to some point ahead of the vehicle. At point *C* on the curve **21** the pressure increment, from *B* to *C* is sufficient that the ambient medium is substantially completely condensed. Alongside the vehicle, the pressure rapidly declines as the pressure wave front within the tube passes this point and pressure reverts to the normal *B* level some distance behind the vehicle. Since temperature is constant this return to the *B* level of pressure revaporizes the condensed medium. That is, along the condensation curve **21**, the pressure is increasing toward the vehicle so that the vapor-condensed phase equilibrium shifts toward the condensed phase until, just h ahead of the vehicle, substantially all of the vapor is condensed and the medium exists almost entirely as a liquid (or solid) on the tube wall **12**. Immediately behind the vehicle leading surface, the equilibrium returns to the original level as increasing amounts of vapor are formed with the shift in equilibrium conditions.

The vehicle **20** is shown, illustratively, as having wheels **22** mounted to travel along bearing surfaces **23** on wall **12** to guide and support the vehicle. A shoe **24** is provided atop the vehicle to connect through third rail **25** to electric power supply **26** for running onboard services such as lights and air-conditioning as well as for powering electric motors (not shown) in the vehicle for driving the wheels **22**.

Jet structure generally indicated at **28** is mounted on the rear of the vehicle including a scoop **30** extending slightly beyond the periphery of the vehicle **20** for gathering in medium as the vehicle moves therethrough. The medium is passed along the scoop through heater section **32** where it is heated and expanded and jetted through orifice **34** in a thrust state to develop propulsive power.

In order to maintain the interior environmental integrity of the tube, receipt and discharge of payloads is accomplished in locks. In FIG. **1**, there is shown a station **38** for loading and unloading vehicle **20** including front and rear gates **40** slidably mounted in gate chambers **42**. These gates seal off the section **44** of the tube **10**. When sealing is complete, passageway **46** advances on rolling seals **48** to portal **50** of the vehicle where seals **52** engage the vehicle side. Simultaneously gate **54** slides into gate chamber **56** to communicate the vehicle's interior through vehicle door **58** with the outside atmosphere indicated at **60**. No outside atmosphere enters the section **44** lock area. Following loading operation, the procedure is reversed and the vehicle again moved through the tube. Make-up medium can be supplied by pump **62** from reservoir **64** if needed in the lock.

For freight operation the foregoing illustrative structure may be simplified to provide a long smooth-walled tube, like a conventional epoxy resin lined gas or other fluid transmission pipe generally about 2 to 4 feet or more in diameter, with mechanical or hydraulic booster stations distributed therealong to propel the payload vehicles forward. Such tubes can run directly to user's plants from supply centers eliminating much freight handling. The vehicles may cruise substantial distances between stations without i.e. without continuous propulsion, because of the substantial absence of drag.

In summary, the invention provides method and apparatus useful for a mass transportation system in which the heretofore existing technology limit of ground related transportation, namely speed limitation due to aerodynamic drag is overcome by application of thermodynamic principles. A controlled environment such as a tube having a selected medium is provided including in a preferred embodiment, a low molecular weight normally liquid compound like water which exists in near equilibrium with its vapor at low pressures and at ambient earth temperatures, e.g. 68° F. Advance of a vehicle through the tube alters the pressure conditions locally in advance of the vehicle so that the vapor is condensed against the tube wall, effectively evacuating the tube. The heat of condensation is removed from the tube by maintaining the tube wall in an isothermal condition as by heat conductive contact thereof with a constant temperature body such as subsurface earth.

We claim:

1. Method of passing an ambient gaseous medium enclosed within a space defined by a wall around a vehicle passing therethrough which includes condensing said medium locally in advance of the vehicle against said wall, maintaining said medium in the condensed phase locally adjacent said vehicle during relative movement of said medium and said vehicle and restoring said medium to its normally ambient condition to the rear of said vehicle.

2. The method of claim **1** wherein portions of said wall adjacent locations of medium condensation are maintained in an essentially isothermal condition.

3. The method of claim **2** wherein an essentially constant temperature body is in heat-conductive relation to said wall.

4. The method of claim **3** wherein said body is water.

5. The method of claim **3** wherein said body is the ground.

6. Method of operating a vehicle in an elongated confined space having an ambient gaseous medium therein including advancing said vehicle within the medium in the space and condensing said medium locally in advance of the vehicle to reduce aerodynamic drag thereon.

7. Method according to claim **6** including confining said medium within a boundary defining a path of vehicle advancement, and pressurizing said medium by advancement of the vehicle thereagainst to effect condensation of said medium.

8. Method claimed in claim **6** including also removing phase-change-produced heat from said space.

9. Method claimed in claim **6** including also restoring said medium to the gaseous condition to the rear of said vehicle.

10. The method of claim **6** comprising the additional step of providing the vehicle with propelling means including a jet structure to receive the condensed medium and to expel the medium in thrust-producing state.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,566,800 Dated 2 March 1971

Inventor(s) Raymond L. Chuan and Norman V. Petersen

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

1. Column 1, line 16: Delete "sea".
2. Column 1, line 50: "$D_a = \beta\beta^2 = C_D A \frac{1}{2} \rho V^2$" should be

   --$D_a = \beta V^2 = C_D A \frac{1}{2} \rho V^2$--
3. Column 3, line 57: "2." should be --1.--
4. Column 6, line 69: Delete "it".
5. Column 7, line 54: Delete "h".

Signed and sealed this 10th day of August 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents