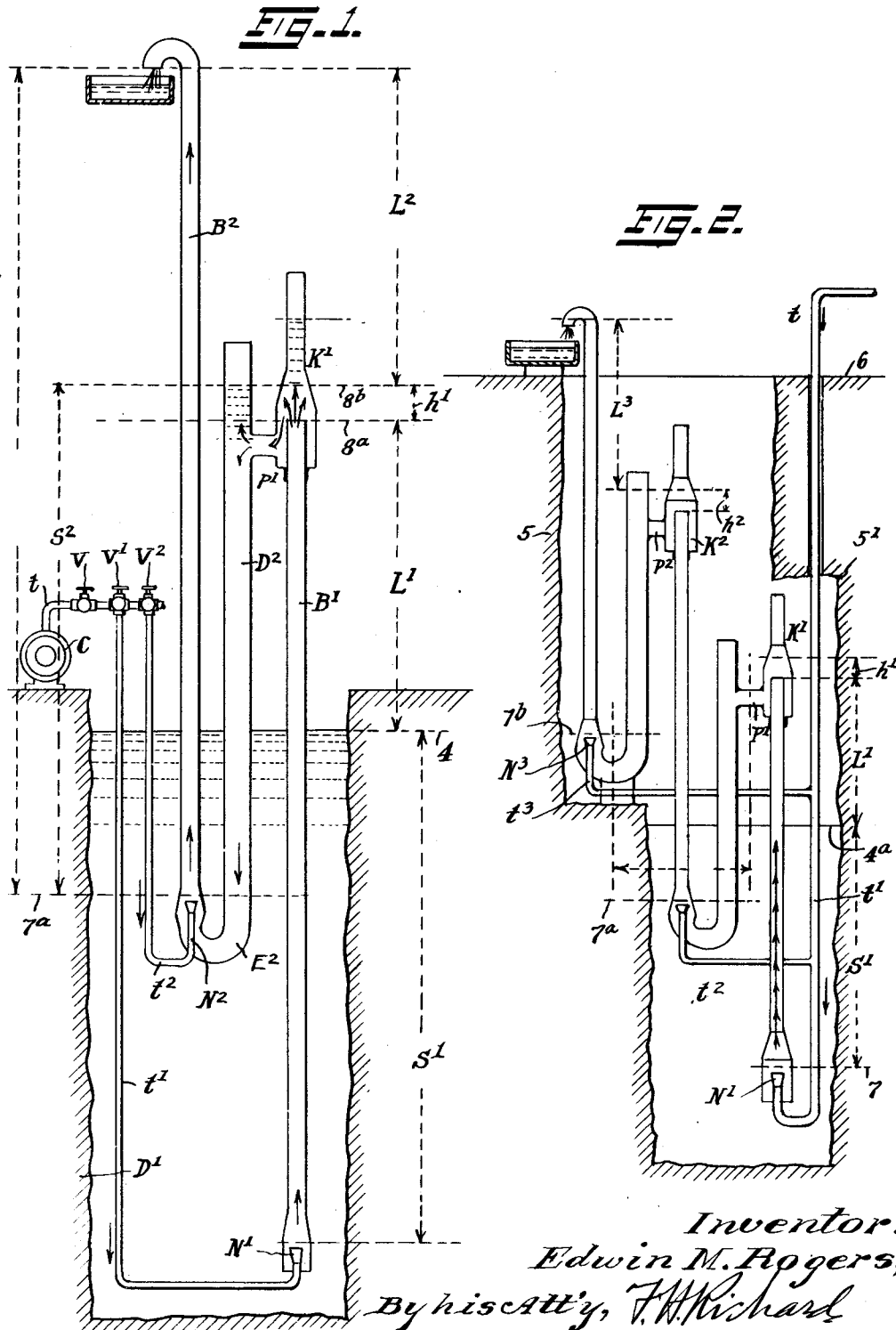


May 12, 1925.

1,537,264

E. M. ROGERS
METHOD OF AND APPARATUS FOR ELEVATING LIQUIDS BY A MULTILIFT
UNIFLOW AIRLIFT SYSTEM
Filed March 24, 1923

4 Sheets-Sheet 1



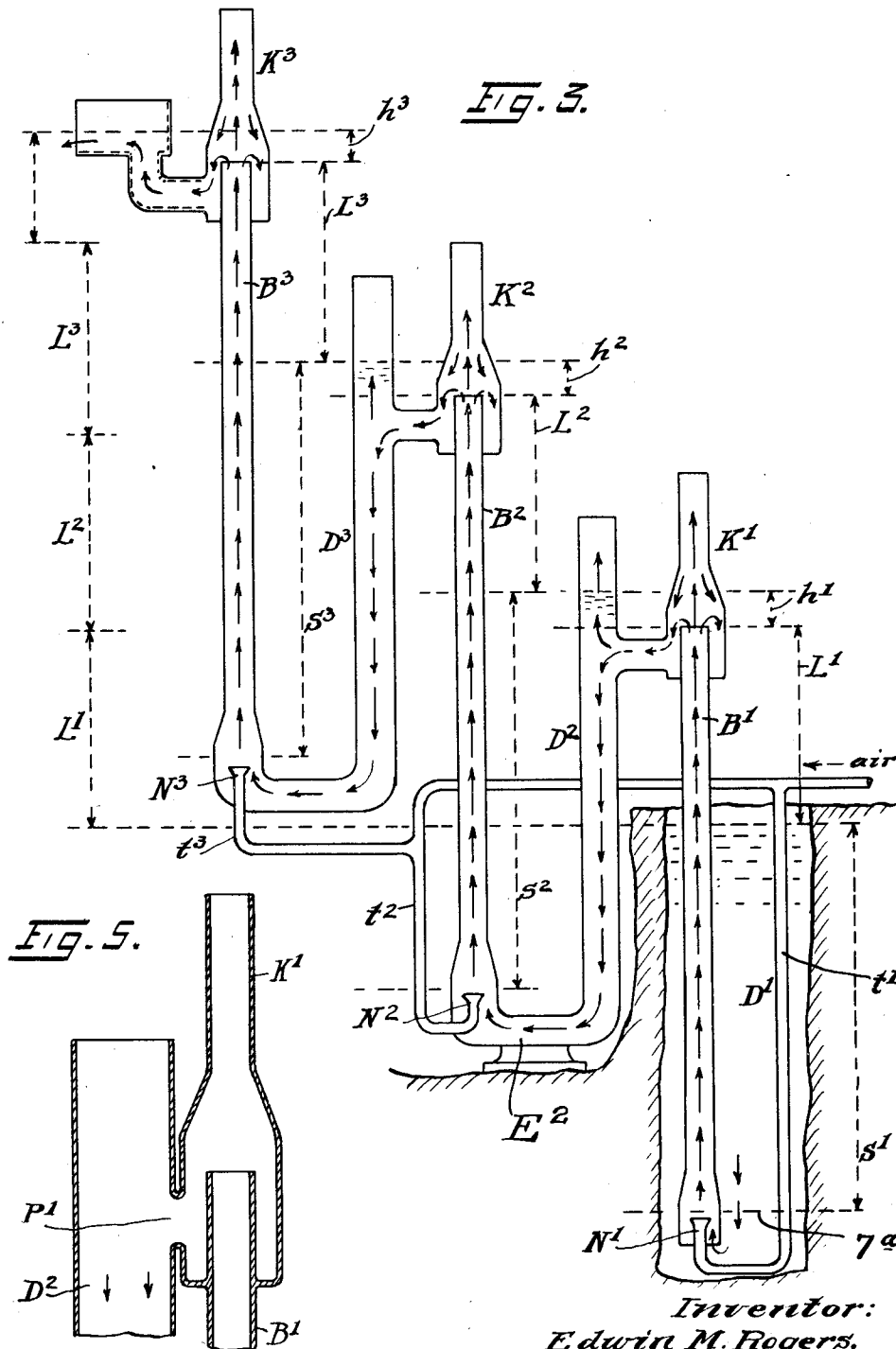
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4 Sheets-Sheet 2



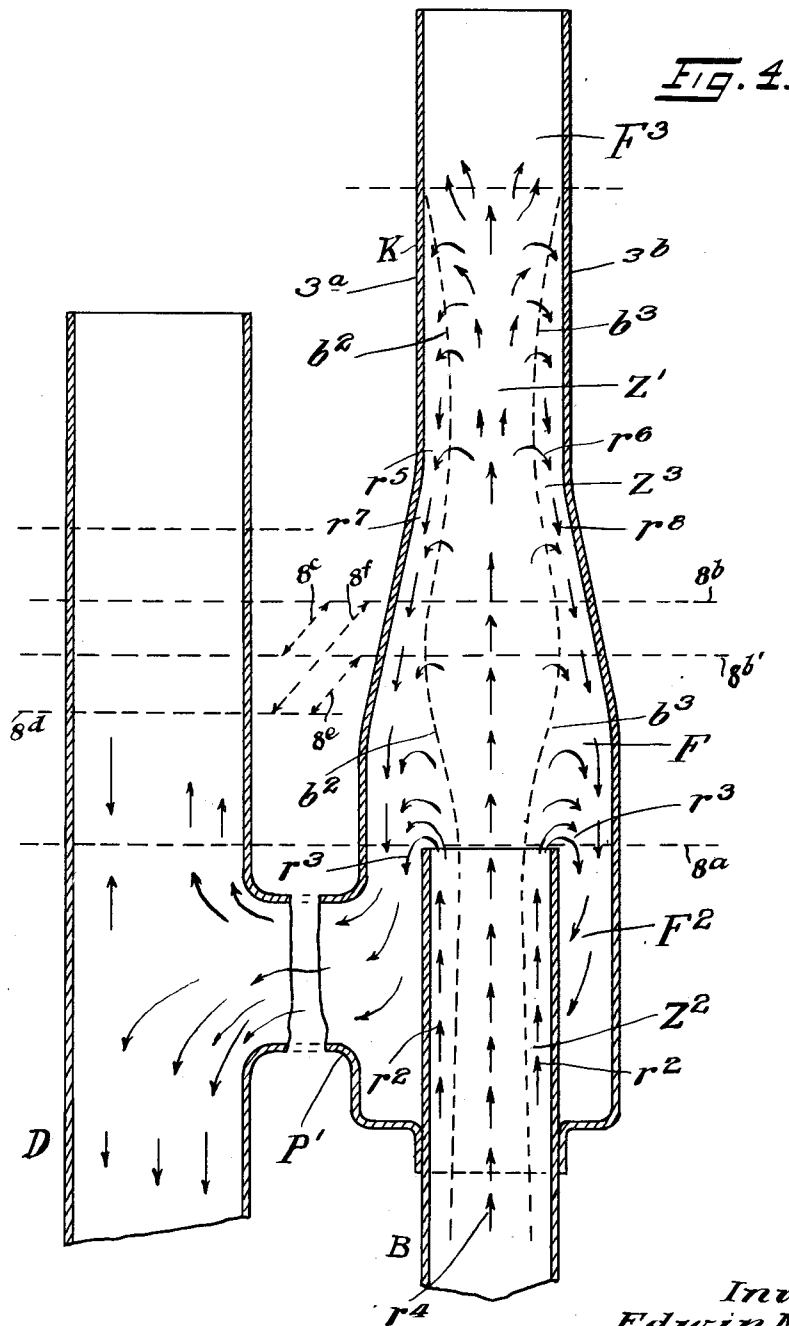
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4 Sheets-Sheet 3



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4 Sheets-Sheet 4

Fig. 4.^a

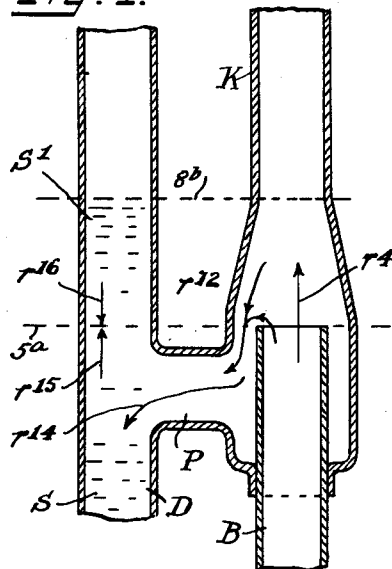


Fig. 4.^b

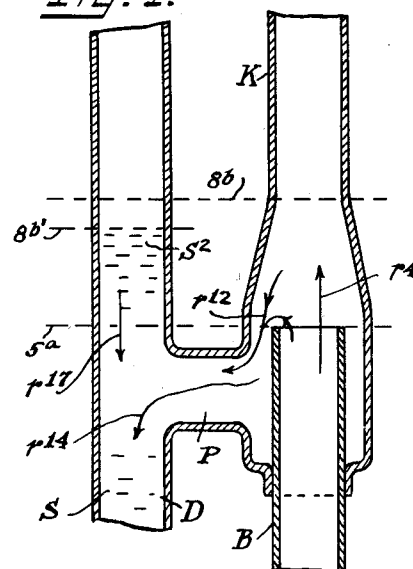


Fig. 4.^c

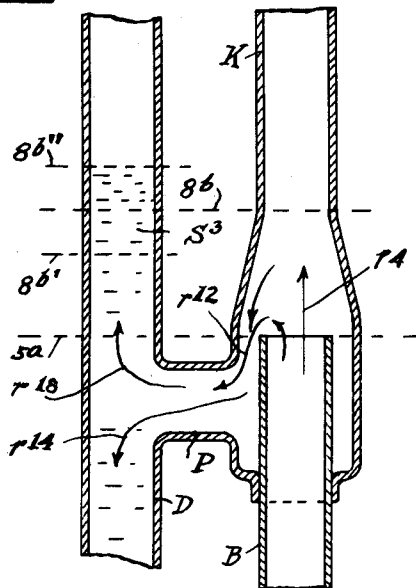
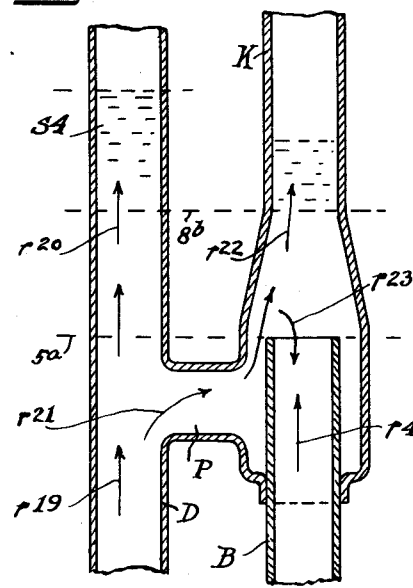


Fig. 4.^d



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Patented May 12, 1925.

1,537,264

UNITED STATES PATENT OFFICE.

EDWIN M. ROGERS, OF NEW YORK, N. Y.

METHOD OF AND APPARATUS FOR ELEVATING LIQUIDS BY A MULTILIFT UNIFLOW AIRLIFT SYSTEM.

Application filed March 24, 1923. Serial No. 627,405.

To all whom it may concern:

Be it known that I, EDWIN M. ROGERS, a citizen of the United States, residing in New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of and Apparatus for Elevating Liquids by a Multilift Uniflow Airlift System, of which the following is a specification.

The present improvements relate to the art of elevating liquids by means of the airlift, and to improved methods and apparatus whereby to effect the air-lifting operation in a continuous and economical manner, and especially by an improved multi-stage operation under the control of an interactive regulation and thereby secure a highly effective mode of action, and an adaptability for successful use under a wide range of conditions, and for practically and rapidly elevating liquids to unusual heights in proportion to the initial submergence and while greatly reducing the losses, especially the waste of power, normally and hitherto resulting from the use of the air under a high degree of compression.

A leading object of the present invention is to furnish a method of air-lifting liquids whereby the liquid to be elevated may be initially received in a stream at the lower end of a primary uptake pipe, and then be conducted through any required number of successive elevation-stages to an outlet for final discharge, and be so conducted while maintained (throughout its path or course) in the form of a continuous stream not subjected, first, to dispersion and then to reformation while the stream, in passing through successive uptake stages, is subjected to successive aerations and de-aerations. Since, by means of this method, the flow of liquid continues in a highly constant and uniform manner hitherto not practically attainable, I have herein designated this peculiar and continuous flowage of the liquid as a "uni-flow" stream.

A further object is to provide a liquid-elevating apparatus in which the described uni-flow stream may be conducted in a continuous stream-form throughout its entire path or route from inlet to outlet, and be therein forwardly impelled by successive submergence-effects combined and coactive with corresponding aerations and de-aeration stages; and which, for realizing this

method and result, shall subject the uni-flow stream (continuously while in operation) to the controlling effect of a plus-atmospheric pressure at all points in the said path thereof, and, also, to an interactive regulation of flowage and of submergence-effects in all (or in any desired plurality) of said successive stages.

A still further object is to furnish such an apparatus provided with means for obtaining said plus-atmospheric pressure, and an effective interactive regulation by the aid of a method of energy-conversion, whereby the kinetic-energy of a spouting column may be utilized at each (or at one or more) of the de-aeration stages, for thereby producing a super-head pressure in an outlet channel of, and at the junction of, an uptake column with a next following and down-flowing submergence column, and for thereby also forming a liquid-column super-head supplemental to an otherwise normal submergence-head, so that at each down-turn portion of the uni-flow stream the movement thereof will take place by a continued stream-form flowage and while maintained under the super-head pressure.

A further object is to provide an airlift system comprising successive single airlifts (whether these are two or more in number) which shall be arranged in the system, and shall coactively operate as airlift pairs having the airlifts thereof connected for interactive regulation; and, for thus purpose, also to combine and connect the uptake column of one said airlift (this column being longitudinally elastic by reason of its aeration) with the submergence column of a next following airlift, (this submergence column being, normally, longitudinally non-elastic owing to its relatively non-aerated condition), and so provide, (as hereinafter explained), for a time-interval to occur between certain of the inter-regulative functions, whereby to obtain a highly effective conjoint regulation as between a super-head portion of the submergence column of one airlift and a super-head pressure in a combined de-aerater and kinetic-energy converter of a preceding single airlift of the system.

It is also a further aim and purpose of the present invention so to employ the numerous advantages peculiar to said method, and so to organize and operate the apparatus as a

whole and in detail, as to minimize the losses hitherto normally incident to the air-lifting method and to improve the character of the cooperation and functioning of the method and apparatus, for thereby securing an aggregate efficiency, and dependability of action, whereby this method may be substituted,—practically and with commercial advantage as to operating cost and maintenance,—for the ordinary and much more expensive pumps or like machines for either temporary or permanent use in raising water from mines and wells, and especially wherever this kind of work is required to be carried on upon a varying scale either intermittently or constantly.

A further object is to furnish, as a composite element for and in a more extended system, a two-stage airlift arranged in the form of an airlift pair which comprises an improved primary airlift so combined and cooperating with a secondary airlift that these two component air-lifts will operate not merely singly or each individually and by itself, but will operate together conjointly and in an interactive and inter-regulative manner, and thereby function as a single apparatus having continuity of organization and action.

Also, one object is to furnish an improved primary airlift, or single system-member, for use as one member of the described airlift pair, and to provide this primary member with a structural arrangement or means constituting a combined de-aerator and kinetic-energy converter, whereby an initial uptake column of aerated liquid,—during a normal operation of the system,—shall be laterally enclosed throughout the entire height thereof, within a conduit which includes an upper conduit-portion or length wherein the de-aeration is normally effected in conjunction with a utilization of the kinetic-energy of a spouting column to form and maintain (during normal operation) a super-head pressure transmittable as a continuing force and with a plus-atmospheric pressure, to a next succeeding airlift member of such a pair, and thence in the same manner to a next following airlift of a multi-pair system. Thus, as hereinafter more fully explained, the apparatus comprises means for transforming the kinetic energy of the discharging water and air into pressure and thereby conserving, or restoring, a part of the head otherwise lost; and transforming into actual head such energies as are latent in, or result from, the disturbances incident to the de-aeration process and to the transferring of the liquid from one airlift-member to another of them in a multi-stage system.

A further object is to provide a peculiar and perfected organization of the said apparatus and elements thereof, in which those

elements, including the several conduit members appurtenant to the apparatus, shall be so connected into one continuous but multi-stage system, and shall be so co-active in this system for the inter-regulative control of the operation thereof, that the liquid may be air-lifted to relatively great elevations by short stages comprised in the single and continuous uni-flow stream, and shall thus operate with an economy incident to the use of low-pressure air, and also so operate without the loss or discarding, at any point, of any increment or residue of un-utilized air-pressure, and without the employment or aid of any mechanically-operable floats or valves, or other movably-acting regulators or stream-controlling devices, whether or not adapted for directly or indirectly affecting either pressures or stream-flow.

While the various phenomena involved in or incident to the operation of the system, or to the operation and interactive regulation of the airlifts comprised therein, or to the several components and devices appurtenant to those airlifts, may not as yet, or in all respects, be fully known or understood, nevertheless, from a considerable experience with airlifts as employed in mines, and from special investigations and practical tests of the present improvements, it is believed that the following description properly explains the nature and mode of action of this unitary airlift system and of the several elements thereof, in connection with the accompanying drawings, in which—

Figure 1 is a side-view, or elevation (assumed to be drawn mainly in section) illustrative of a two-stage airlift system arranged and operable in accordance with the present invention. In this view, for convenience of illustration, (and following a conventional practice), the longer tubes and conduit members are shown greatly reduced in length in proportion to their diameters, as compared with the relative lengths and sizes thereof heretofore more commonly used; this expedient is deemed to be necessary in order to more clearly represent the relations of the several elements in a preferred organization thereof. For instance, the diameter of pipe B¹ is here shown having a diameter of nearly one-twentieth of its length, whereas in practice said diameter often may be only two to four inches,—though in some instances very much larger,—while almost any length may be used; lengths of from fifty to one hundred feet are sometimes employed, depending upon the conditions and requirements in any particular instance.

Fig. 2 is a side-view similar to Fig. 1 (but drawn on a smaller scale) for showing the same general arrangement when this is extended into a three-stage system having

the component air-lifts thereof positioned, equipped and connected for an automatic and interactive regulation.

Fig. 3 is a side view analogous in arrangement to Fig. 2, for more fully illustrating the method of operation of the system and the principles thereof; and, for explaining the several coactive means and functions whereby there is obtained an inter-regulative control which extends throughout this multi-stage apparatus.

Fig. 4 is an enlarged and more complete view of the upper portion of a primary air-lift of the form shown in the preceding views, and illustrates certain relations and phenomena as hereinafter explained, regarding the spouting-column and the peculiar method and means provided for utilizing the kinetic energy thereof while maintaining a uni-flow stream, and whereby said upper portion becomes an energy-converter and operates in the multi-stage system as an economizer-regulator.

Figs. 4^a, 4^b, 4^c and 4^d are a series of diagrams supplementing Fig. 4, and further illustrate functions hereinafter explained in connection, more especially, with Figs. 3 and 4.

Fig. 5 illustrates how one detail of the apparatus may be modified in ways and for purposes as hereinafter set forth.

Similar reference characters designate, or indicate like parts or lines, in all the views.

In the arrangements of air-lift apparatus shown in the drawings, successive uptake columns are designated, in the order of their action, by B¹, B², and B³, respectively; and, the respective submergence containers therefor are designated by D¹, D² and D³. This container, or receptacle, for uptake column B¹, may consist, as here illustrated, of a pit, or well, D¹, into which the liquid is collected and in which said column B¹ extends downwardly in a manner commonly employed in locating ordinary air-lift in mines; the height of the submergence is here indicated by the water-surface line 4. For the uptake columns B² and B³ submergence containers in the form of tubular columns, as D² and D³, are deemed to be preferable, these being suitably positioned and connected substantially as indicated.

Said uptake column, or pipe, B¹, is considered to be the primary uptake column, since this initially receives all the liquid to be elevated; and when deemed to be desirable, the liquid may be supplied to this column, B¹, by a tubular form of submergence container, such as D², which thus becomes an equivalent or substitute for this purpose, of the shaft or well D¹.

In practice, the several tubular columns, and the accessory devices therefor, may be supported by any suitable means, such as foundations and retaining members (not

herein shown), these being arranged and connected in accordance with principles and methods already well-known in the art of pumps and air-lifts; but, to simplify the illustration of the principal elements and features, those ordinary means are not herein fully shown or described.

In some instances a "single" arrangement of the air-lift may be used, this comprising a "primary" uptake column, as B¹, and having suitable submergence-supplying and air-supply means therefor. This single air-lift, when equipped and arranged in accordance with the present invention, will be provided at the upper part of its said uptake column, with an energy-converter, and, preferably, with a supplemental-head-conserving means, these two devices being illustrated, each in a preferred form thereof, in Fig. 4 and Fig. 5, respectively, and hereinafter more fully explained.

Generally, however, in order economically and practically to meet the more usual present-day requirements, it is important, and often necessary, to employ a plurality of air-lifts arranged in series, and thereby deliver the liquid to a considerable elevation. In Fig. 1, the present improvements are shown thus applied to a two-stage system in which the liquid is conducted in a uni-flow stream. In this arrangement (Fig. 1), the submergence "column," or well, D¹ and connected uptake column, B¹, are comprised in the first air-lift; and, the tubular submergence column D² and connected uptake column B², are comprised in the second air-lift. These two air-lifts, each connected and furnished for co-active and inter-regulative operation, together constitute one "air-lift pair," as hereinafter more fully explained.

The system illustrated in Fig. 1, is shown in Fig. 2 extended into a three-stage system, this comprising three air-lifts, or air-lift-members of the series. Each of these air-lifts comprises an uptake column and a submergence container therefor; and, all are connected and furnished for coactive and inter-regulative operation similarly as described in connection with Fig. 1. As in Fig. 1, the column B¹ is here the "primary" uptake column of the first air-lift-pair, and the submergence is shown to be obtainable by extending the column B¹ downwardly in the liquid-collecting well D¹ to a proper distance below the line 4, which (as in Fig. 1) represents a normal water level. Also, in Fig. 2, the entire multi-stage system is indicated, by the walls 5 and 5', as being located mainly below a ground-surface line 6 and in a shaft or chamber analogous to those common to mines and quarries.

In the present multi-stage system, the entire apparatus may be regarded not merely as a series of individual air-lifts peculiarly connected for coactive operation, but also as

a single "air-lift" in which one stream is successively actuated, and in which successive portions of the air-lift structure so control the operation of successive portions, respectively, of said single stream, that these stream-portions become the operating instrumentalities and coact with and upon each other for effecting the inter-regulative control of all the stream-portions, and thus
10 of the stream as a whole.

Before proceeding further with detailed explanations of the foregoing features and of their modes of interaction for effecting the inter-regulative function, some incidental matters should be noted:—

The function of the air bubbles being to lighten the liquid content of the uptake column, so that the weight thereof will be over-balanced by the weight of the submergence head, it is obvious that any available gases may be used in place of atmospheric air, and hence it is to be understood that the term "air" is herein employed as a generic term for designating the air or other gas
20 which may be in any given instance available for use, or be used, in effecting the necessary reduction in the weight of the fluid contained within a given length of an uptake pipe.

The aerated uptake stream on passing above the upper end of an uptake pipe, issues as "the spouting column," and the process of de-aeration is only completed at the upper end of this column, and within
30 the energy-converter apparatus, as K.

The term "spouting head" is intended to refer to the height of liquid contained in the spouting column, if this liquid should be considered, or measured, by the reaction
40 effect or pressure thereof downwardly at the level of the discharge end of the uptake pipe. For instance, supposing that the spouting column (see Fig. 4) might have an extreme height of seven feet, but contain
45 such a quantity of air so distributed therein as to have a pressure effect at said pipe-end level only equal to a liquid column three feet in height, then this "head" of three feet
50 would be the "spouting head," and would represent the pressure effect transmissible for producing a supplemental head in the submergence column of a next following air-lift.

In the practical operation of an ordinary airlift series, sometimes the working conditions will be modified in such a manner or to such an extent as to change the rate of upflow,—that is, the rate of action, or discharge,—and thus for a time cause some
60 one of a series of the airlifts to have an undue excess of action as compared (at such a moment) with another of them. These variations, sometimes, heretofore, have been regulated by means of mechanically-operable governing devices applied to the sev-

eral component air-lifts of such a series. In the present system, however, no such governing devices are required, owing to the inter-active control by which the heads and pressures are now made conjointly operative and inter-regulative, for thereby effecting the necessary control by an auto-governing action which extends to the system as a whole, and also applies to each of the individual airlift-members thereof. These results are
70 now attained, as hereinafter explained, by means of a combination of coactively-operating structural features which has the function of an oscillation governor, said features being arranged for restricting,—or rendering less active than otherwise would be normal,—such oscillations of pressure and flow-
75 age as may occur from time to time, in either one or both of the airlifts of an airlift pair, and thereby accelerate the process of balancing, or re-balancing, an unequal operation of successive airlifts, (or of any pair of them), whenever either one of such a pair may have been materially changed in its rate of action relative to the other.

The several uptake pipes,—these being uptake-stream containers,—are designated, (in Figs. 1, 2 and 3), by B^1 , B^2 and B^3 , for indicating the respective positions in the system of this series of similar members, of which one may be designated individually but without choice, as the pipe or column "B." In like manner the submergence columns may be designated individually but without choice, as column "D"; and, the
90 members K^1 , K^2 , K^3 , may be so designated by "K," and especially in connection with Figs. 4 to 4⁴ inclusive. On the same principle, any one of the aeration nozzles may be referred to as nozzle "N," and any air-supply pipe therefor, as pipe "t"; and similarly, any of the columns-connecting conduits, or ports p^1 , p^2 , p^3 , may be designated by "P" whenever this may be sufficient, or consistent in view of the context; this
100 method may also be extended to other details common to a plurality of the air-lifts of the system.

In Fig. 1, the uptake column, B^1 , is shown provided with a stream-conductor pipe, P^1 , which constitutes a side-outlet port,—also designated as a transfer-conduit,—connected for delivering the main-stream into the next following submergence column, D^2 . Similarly, in Figs. 2 and 3, the same columns B^1 and D^2 are shown connected in the same manner; and, the uptake column B^2 is here shown connected in like manner with submergence column D^3 by a pipe, or transfer-conduit, P^2 . These stream-transferring conductor-pipes, P^1 and P^2 are also each shown in a sub-surface position, for thereby transferring the uni-flow main-stream for one to a next following airlift while this stream is maintained at all points under a
110 120 125 130

plus-atmospheric pressure. This plus-pressure, in practice, preferably should be greater than the pressure-variations liable to occur within the uptake and submergence columns by or during the co-active operation thereof; hence,—as hereinafter explained,—the submergence super-head should be of sufficient height and quantity for effecting this result. Above, but adjacent to, said stream-transferring conduits or passageways, P^1 , P^2 , said uptake columns B^1 , B^2 , are shown each provided with an apparatus having the function of an energy-converter, as K^1 and K^2 , respectively, each of which forms the upper-end portion of an uptake column. This device, or converter, has the function of a de-aerator, and operates to produce the submergence super-head, as h , a preferred form of the apparatus being hereinafter more fully explained, particularly in connection with Fig. 4.

The uptake columns, B^1 , B^2 , B^3 , are shown in the accompanying drawings as being each provided at the lower end thereof (see Figs. 1 and 2) with an aeration device, or "nozzle"; thus the latter term is here used generically. These aeration devices, (whether or not having the usual form of a nozzle), are symbolically indicated at and by N^1 , N^2 and N^3 , respectively, and in practice any of the well-known kinds of stream-aerating devices, or air-lift nozzles, may be adapted and employed for the present purposes. The nozzle at N^1 operates to initially aerate the stream when this is entering column B^1 , and the nozzles at N^2 and N^3 operate to re-aerate the same stream (subsequent to a de-aeration thereof) at successive points in the uni-flow course, or path thereof. In Fig. 3, these several nozzles are presumed to have effected such aeration (each at its respective position) at and upwardly from the lines 7, 7^a, 7^b, respectively (Figs. 1 and 2).

For the purpose of supplying the air to the nozzles, the present air-lift system may comprise, as an element thereof, any of the well-known arrangements of air-supply apparatus such as already employed in ordinary air-lifts. For instance, as indicated diagrammatically in Fig. 1, the uptake pipe, or column, may be suitably air-supplied by means of some ordinary air-compressor, as C , of suitable location and capacity, and which may be connected by air-distributing pipes t^1 , t^2 , t^3 , to the aeration devices or nozzles at N^1 , N^2 , N^3 , for the uptake columns B^1 , B^2 , B^3 , respectively. These air-distributing pipes are shown supplied, in Fig. 1, by a main pipe, t , leading from compressor C ; in Figs. 2 and 3, the pipe t is supposed to come from an air compressor not shown in these views. For regulating the action of the several nozzles said air supply pipes may be each provided (at some, or any, con-

venient point therein) with an ordinary flow-adjusting valve or regulator, as indicated at V^1 , V^2 (Fig. 1), respectively; also the compressor, or a pipe as t , therefrom, may have a main-valve, as at V , whereby to regulate, and to let on or cut off, the whole air-supply at once. However, in some instances these valves may be omitted (as for instance in Fig. 2) if the pipes are ample, the nozzles sufficiently uniform, and each nozzle accurately located at a proper relative elevation.

For convenience of description, and to facilitate clearness of illustration, the several principal members of the airlift pair have been shown in Figs. 1, 2 and 3, arranged side by side and at relatively considerable distances apart, but it should be understood that in practice, whenever found to be desirable, the several members, and especially the uptake pipes B^1 , B^2 , and the submergence columns therefor, may be placed close to each other, or even more widely apart, according to the conditions attending any particular location or the preference of the constructor. One effect, evidently, of placing pipe B^1 and said column D^2 close to each other, is to shorten the distance through which the counter-flow stream has to travel in passing from the de-aeration chamber, as K^1 , laterally through port P^1 and into said column D^2 ; an illustration of one such close form of assemblage is shown in the small sectional side view, Fig. 5.

By extending this uni-flow system from a single airlift-pair, as in Fig. 1, to include three successive air-lifts, as in Fig. 2, a further and important improvement is thereby accomplished, since,—in this more extended system,—the plurality of three coactively-connected airlifts not only comprises three "column pairs" (each forming one air-lift), but also comprises a plurality of airlift pairs.

For instance, in Fig. 2, (also in Fig. 3), the three single airlifts are arranged first, into two pairs, and these pairs are arranged with one air-lift member common to both pairs. The primary airlift D^1 , B^1 , is arranged and connected for delivering liquid to a second airlift D^2 , B^2 , that in turn, delivers the same liquid to a third airlift, D^3 , B^3 . Thus the series of three airlifts is here shown arranged in two successive pairs, in which the secondary airlift, as D^2 , B^2 , of the first pair is also the primary airlift of the second pair; all three of these airlifts are herein indicated as being arranged,—in this instance—for operation by air of the same pressure. Also in this triple system, there are two of the energy-converter apparatuses which are also herein described and designated as a combined energy-economizer and oscillation governor. These two apparatuses, as K^1 , K^2 , are shown coactively con-

nected each with other through an intervening uptake column, as B^2 , (Fig. 2), which is operated by a submergence, as D^2 , that is supplied from said preceding uptake column B^1 , and is in part regulated by means of the first of said combined apparatuses; this auto-governing mode of action (heretofore mentioned) is hereinafter more fully explained.

In said triple-arrangement of Fig. 2, each of the uptake columns operates under a different condition from the other two. In the first airlift, said column B^1 is supplied from a normally fixed submergence level, as 4^1 , and discharges against a spouting-column head (in column K^1) that is subject to a governing action; in the second airlift, the uptake column, B^2 , is supplied from a submergence column D^2 , which is subject to a variable but automatically-regulated pressure or head, and discharges against a spouting-column head, (in de-aerator column K^2) in the same manner as said column B^1 , just described; and, in the third airlift, the uptake column, B^3 , is supplied by and from a submergence column, D^3 , arranged and operating similarly as the column D^2 just described.

Thus the said series of airlifts, while each have distinctly different operating relations from the others, are interactive and adjunctive each with the other two, and therefore are subject, individually and as a system or series, to the aforesaid auto-governing action. Each said airlift of the system, thus may be said to have an individual and primary mode of action normal to its own features and proportions; next, the successive airlift pairs have each a mode and ratio of action, or operation, which may be said to comprise those individual actions plus a variation arising from their interconnection, whereby a change of operating condition obtaining in one member of said pair, acts from time to time, to accelerate or retard the action or ratio of operation of the other said member of the pair. This complexity of the relations and functions, is further increased in the present series-system, by the inclusion therein of a plurality of the sensitive and quick-action apparatuses K , each operating as a "combined energy-economizer and oscillation-governor."

In the three-stage system shown in Fig. 2 (also in Fig. 3), the second air-lift of the series may be said to be, and is herein regarded as being, one form of a stream-impelling connector for receiving the uni-flow stream from the first air-lift and transmitting this stream (as an unbroken mainstream) to the terminal air-lift (here the third one) of the system. Said intermediate stream-impeller is also here shown fitted and proportioned for operation as a second air-lift of the system, and for being operated by

the same air-supply pressure and submergence-effect as employed in the first air-lift column, B^1 , and in the third air-lift column, B^3 , of the system.

However, this three-stage system may be arranged in some instances for using such an air-lift form of intermediate impeller when this is proportioned for elevating the stream through a different proportional distance, or height. This arrangement of the system to use unequal lifts for successive and coactive airlift-members, will be obvious without being herein specially illustrated, and it may be so used advantageously in various locations. In such an instance, it is necessary, of course, that the successive uptake columns, respectively, shall each be provided (or connected) with means for suitably regulating the pressure and volume of the supply of air thereto; for this purpose an ordinary arrangement of compressor, pipes and valves, (such for instance, as herein described in connection with Fig. 1), will usually be ample for such requirements.

When the liquid-aerating air-jets are forced through an ordinary perforated nozzle, (symbolically indicated at N^1) under a pressure somewhat in excess of the pressure normally or actually necessary to effect the required proportionate aeration, these jets frequently operate in practice, after the manner of injectors and thereby impart power, or "energy", to the up-flowing stream and thus produce an upward movement or velocity of the stream in addition to the rate of up-flow due to the aeration itself. While this injector-effect or jet-action may, usually, be the cause of loss of power under the former practice, this action normally has a useful effect in the present system, since, by its increase of the range of normal action, it thereby lessens the danger of having an air-lift cease operating, or becoming "stalled",—because of a temporary and small deficiency in the degree of said aeration. This useful effect may now be advantageously and fully realized owing to the effective manner in which the energy of the spouting column,—including said injector-effect or energy,—is converted into pressure in the energy-converter member, as K^1 , or K^2 , of an uptake column, as B^1 or B^2 . For this purpose said converter member should have the laterally-enclosed de-aeration column or chamber thereof, of a sufficient height, and otherwise be proportioned and have a capacity, ample for treating the normal spouting column when this is moved up in said member, as K^1 , by a distance, or extra head, corresponding to said injector-effect. Thus it now becomes practicable to use an excess of injector-force, with an ample aeration, and also to use a full measure of submergence, thereby insuring a more advantageous operation as a whole, since

all the excess and residual energies so transmitted can now be effectively converted into a pressure which acts to raise the submergence superhead to a height compensating for these, otherwise, cumulative losses.

In this connection it will be remembered that in ordinary airlifts having a single-lift uptake pipe, when the aerated liquid emerges from the discharge-end of this pipe, the air content thereof expands instantly while the liquid content flows out, usually in a spouting manner. Thus the de-aeration is there effected in a relatively violent manner, and whatever kinetic energy is contained in the out-pouring liquid of the "spouting column" is lost, only the liquid itself being saved. Contrary to that method and practice, in my present improvements the aerated liquid of the upflowing stream is closely retained in a columnar form or status until the upflow movement ceases and the de-aeration is completed, and at this time only the separated air is discharged at the top, while all the liquid is returned downwardly for a distance, and then is disposed of by and in a flowing stream and without any spouting or overflowing action, and hence with no loss of energy consequent thereto.

Thus, by means of my present improvements, the total efficiency may be increased by operating the primary airlift in a manner which otherwise would result in a loss. To thus increase the efficiency of the operation in the uptake pipe B, necessarily (under the practice hitherto) increases the loss due to the discharge of an unduly large quantity of energy in the spouting column. But, by the conversion of the spouting-column energy into a coacting pressure, that loss is retrieved, and is then made available and effective for increasing the otherwise net efficiency of the airlift pair, and of the multi-stage system, considered as a whole.

From the foregoing description as illustrated, it will now be seen that in an interconnected series of three airlifts, (as in Figs. 2 and 3) each of the uptake columns has a different operative relation in and to the system. The first said column, B¹, initially receives the liquid, and hence may take up more or less in quantity, in a given unit of time, according to variations in the operation conditions; the third said column, B³, receives only the discharge from the second airlift, and discharges that quantity not to be used again in the system; and, the second said column, B², operates only as one member of an airlift-transmitter intermediate to the first airlift and said third one, thus receiving whatever quantity is supplied to it, and delivering only this same quantity to said third airlift.

However, owing to the herein described interactive method of regulation, the first airlift cannot continuously over-supply the

second airlift, since at the beginning of such an action, the immediate effect thereof is to check the rate of action of the first airlift and thereby prevent a continuance of such an over-supply; this result, however, may be modified to some extent, and within the range of normal working conditions, by some degree of increase, for a brief period, in the rate of action of the second airlift. On the same principle, but in a modified manner, the third airlift normally operates to check the rate of action of the second airlift, (but in some cases to permit acceleration thereof), should the latter tend to strongly over-supply the third air-lift.

Thus the second airlift may be restricted or regulate the rate of action of the first one. Also the first one may be restricted in action, or released to act more freely, but the action of the second airlift after this second action has been modified by the third airlift; in the latter case, said restriction or modification of the action of the first airlift results from a conjoint action of an airlift-pair which comprises said second and third airlifts of the system.

In Fig. 3, the third uptake column, B³, is shown elevated (above its otherwise normal position) to a position for securing the gain equal to the sum of the two supplemental submergence-heads h^1 and h^2 of the two submergence columns D¹ and D², respectively; these gains being obtained from the conversion,—as already explained,—of the kinetic energy in the spouting-columns. Thus, said energy transferred to submergence column D² permits column B² to be placed higher (than otherwise normal) by the pressure-head height h^1 ; and, similarly, column B³ may be placed higher, by the amount of head, or height h^2 .

In this connection it will be remembered that in an air-lift uptake-pipe, the up-flowing stream comprises two elements or currents, one being a liquid stream-component and this being aerated by the stream of air. This air, however, is normally in a comminuted form, or in "bubbles", which not only move upwardly with the liquid stream but also have a further upward or "floatation" movement in (and relatively to) the liquid, and commonly designated as "slippage". In practice, the rate,—or velocity thereof relatively to the liquid,—of this "slippage" of the air bubbles necessarily varies, and may arise from various causes; also the rate and extent of their coalescence similarly varies. Also, these variations may occur from time to time, (from moment to moment), not only in the rate of slippage, but also of the proportionate volumes of air and liquid contained within or delivered by an uptake pipe, and thereby produce variations in the rate of stream-flowage, and in pressures (at some points or heights within

the columns), which are in the nature of fluctuations, or, as herein considered, "oscillations", either incipient, initial or resultant in character. These phenomena also have to be considered in connection with the normally rapid acceleration of the aerated stream during the ascent thereof within the uptake-pipe, and in accordance with a well-known principle.

Thus it appears that the formation of a spouting column of aerated liquid, takes place in connection with a peculiar changing condition of the mixture of air and liquid during the upflow thereof within the uptake pipe. Owing to said "slippage" of the air bubbles in the liquid, and the normal and well-known tendency of a stream to flow faster in the central portion as compared with the velocity thereof in the outer or peripheral portion, there is normally a constant coalescence of the bubbles by the combining together of several into one, thereby increasing their size and consequent rate of slippage, in accordance with a well-known principle. Then, too, such a large bubble,—since its slippage increases rapidly with its enlargement,—overtakes and gathers into itself more and more of the smaller bubbles, so that in long uptake pipes these losses may (and often do) represent a large waste, in the aggregate, of power and efficiency. A further result of that action is normally to segregate the air more rapidly,—and with a centralizing flow thereof,—near the upper end of the uptake pipe, so that the upflowing column when nearing the discharge end of said pipe may have an outer portion, or peripheral zone (as it would be seen in a cross-sectional view of this pipe) composed of liquid nearly or fully de-aerated; this outer portion, evidently, will tend rapidly to form and thicken around the highly aerated central portion, so that on emerging from said pipe discharge-end only a moderate proportion of the total quantity of liquid may be projected up, as a spouting column, into the converter chamber of the apparatus K.

Having in mind Fig. 3 and the foregoing explanations, it will now be seen that on entering the open lower end of uptake B¹, the liquid stream is aerated in the usual manner by air under a suitable pressure and supplied through an aeration device, as N¹, (at level 4^a), and that being thus aerated the stream is pushed up by submergence-effect (approximately indicated by D¹) toward the upper discharge-end of said pipe, at line 8^a, (Fig. 4). During the upflowing movement of said stream, the air-bubbles rapidly expand, and the velocity of up-flow correspondingly increases upwardly from said point of aeration, while the pressure proportionally decreases; also, the coalescence accelerates on nearing the said

upper pipe-end, while a substantial, or relative, de-aerating action normally proceeds in a peripheral portion, or zone, of the pipe, and thus tends to rapidly form, or develop, a stream-segregating action, so that on reaching said discharge-end of pipe B¹, the main-stream may be regarded as comprising a peripheral de-aerated stream (or one of low aeration), which surrounds a central stream in which an excess of aeration has a high flotation velocity and is concentrating with an accelerating coalescence. Thus, on passing said line 8^a, the said peripheral stream,—this being here practically de-aerated and of a uni-flow character,—readily passes outwardly over the pipe-end (at arrows 7^a, Fig. 4) and thence, (as a branch-portion of the main-stream) flows directly to the transfer conduit, P¹. Simultaneously with that action, the now highly aerated central stream flows upwardly (as another branch of the main-stream) in the form of a spouting column which enters with a high velocity the top-vented column of said apparatus K¹, and therein becomes fully de-aerated, while the liquid thereof is forced outwardly to the enclosing wall, and there is formed into a down-flow stream which on or before reaching said transfer-conduit re-unites with said peripheral stream thereby forming a restored and de-aerated main-stream which flows through said transfer-conduit for supplying the next following submergence-column, as D².

Thus, it will now be obvious that in the apparatuses K, the de-aeration up-flow and down-flow stream (the latter being the "counter-flow" one) may be properly regarded as a branch-stream which comprises only a portion of the main-stream of liquid issuing out from the said upper pipe-end of column B, and of which a main,—or primary,—portion which is substantially unaerated flows directly from said pipe-end, and thence passes forward to the conduit port P¹, and thence into the next submergence column as a continuous uni-flow current. The liquid of said branch-stream is also a stream of a uni-flow character, since this liquid is only diverted temporarily from the main stream-path, (and then only for being segregated from air temporarily associated therewith) and is at no time released from its energy-converting control, but is immediately (and in a continuing manner) re-united with the said main or primary stream-portion, and is then incorporated therewith into said next following liquid submergence-column.

In the upflowing fluid column within pipe B, there is normally a continuous acceleration of the whole stream or fluid column up to line 8^a, (see Fig. 4). In this column below line 8^a, the air-content of the stream accelerates more rapidly than the stream as

a whole, owing to the described "slippage" of the air bubbles in the liquid. Accordingly, it may be said that up to said line, or level 8^a , there is a constant acceleration of the liquid-content, and a greater ratio of acceleration of the air-content of the stream. This relation, however, of the said two velocities or accelerations, is changed when said aerated stream passes above said level 8^a ; from this point the ascent of the air-content continues to accelerate while also undergoing an increasing rate of segregative action, whereas during this same period the upward movement of said liquid-content constantly decreases, until it finally ceases in connection with the formation of this liquid into a counterflow stream.

In the operation of this apparatus (see Fig. 4) functioning as an "energy-converter", or as a "kinetic-energy economizer", the tubular member K, first receives (directly from pipe B), the described excess aerated central stream in the form of a spouting column, together with all (or nearly all) the energy therein, reduces in succession the liquid increments thereof to a state of rest, and then progressively incorporates them into a counter-flow stream, and later delivers this (in some or a sufficient part) through said transfer-conduit, P, to supply, (or re-supply, as the case may be), said pressure-head in submergence column D. Thus, it may be said that the energy discharged out of an uptake pipe, B, with the contents of a spouting column, is economized, (instead of being dissipated or wasted, by being applied to the useful purpose of increasing the pressure-head of the submergence for the next following airlift. This direction of the action, however, is considered as being reversed as regards the same member K of the airlift-pair member, when a particular governing action, or impulse, is initiated from or by a next following uptake column, as B^2 , in Fig. 3. These functions, and the results thereof as regards the governing effects, will now be described more in detail, as follows:—

Referring to Fig. 4, this enlarged and sectional view illustrates in a diagrammatic manner a preferred arrangement of the apparatus K, and the principle and mode of action thereof, as the same are now understood. The uptake pipe, or column, B, has the discharge-end thereof terminating on the line 8^a . This pipe-end 8^a constitutes one channel comprised in that portion, or structure, which is herein sometimes designated as the "three-channel-junction", and of which the aforesaid conduit or port, P, constitutes a second channel, and of which the lower portion, F, of the de-aeration chamber, constitutes the third channel. These three channels, 8^a , P and F, are preferably connected by, or may comprise, a

chamber, F^2 , surrounding the pipe-end 8^a and proportioned for certain coactive functions as hereinafter explained.

Within the opposite side-lines, 3^a , 3^b , of the tubular wall of member K, the two curved lines, b^2 , b^3 , are drawn for indicating a central zone Z^1 and a peripheral zone Z^2 . Said lines b^2 , b^3 are also shown extending well down into the pipe B, for there indicating a downward extension of said zone Z^1 , within a surrounding zone, Z^2 , that is wholly within uptake pipe B; in this zone, Z^2 , the tubular or peripheral, and substantially de-aerated, upflowing stream of liquid (already described) is represented by arrow-lines r^2 , r^2 . This stream, r^2 , on reaching the aforesaid level 8^a normally flows outwardly and then downwardly, over and around the pipe-end 8^a , (as clearly indicated by the curved arrows at r^3 , r^3), and thence flows through chamber F^2 , and conduit P, into the submergence column D, as also indicated (in a customary manner) by successive curved arrows. Said peripheral stream, r^2 , being thus diverted directly into the main flowage path of the uni-flow mainstream, the described central,—and now excess-aerated stream,—here indicated by the single line of arrows, r^4 ,—is free to shoot upwardly through said out-turning portion, r^3 , of said peripheral stream and then spread out as indicated by the outwardly-curved portions of said lines b^2 , b^3 , (between the horizontal lines 8^a and 8^b), and thus pass upward into the columnar de-aeration space F^3 .

On thus issuing from pipe B, said highly aerated central column, or stream, now shoots upward as a "spouting column", and with a velocity, and to a height, due to the kinetic energy therein; and, during this upward movement, the air-content rapidly expands and segregates, while the liquid-content is correspondingly de-aerated. These operations tend to disperse said liquid outwardly,—about as indicated by a series of arrows from r^5 to r^6 ,—and thereby form of this liquid a peripheral down-flow stream indicated by the line of arrows r^7 , r^7 ; these arrow lines also indicate how the said liquid-content of the spouting column, after de-aeration thereof, is formed into a peripheral and counter-flow stream which passes downward within the walls 3^a , 3^b , and into the space F^2 , and there re-unites with said peripheral stream, r^2 , from the pipe zone Z^2 , and from thence passes through conduit P into the submergence column D. While the spouting-column is thus flowing upward, it is continually and progressively de-aerating.

These processes being continuous (during operation of the airlift) there seems first to be formed a de-aerated film or sheet of liquid (on or near the inner surface of the tube) which flows down, (as indicated by

said arrow lines r^7 , r^8) with a gradually increasing thickness until it enters the passageway space at level 8^a in the form of a counter-flow stream. At this time and position, therefore, the quantity of such down-flowing de-aerated liquid corresponds with the quantity of spouting-column liquid flowing upwardly (at level 8^a) from within the discharge end, 2^a , of pipe B. Thus one result of the apparatus in operation, is to form the counter-flow and pressure-head stream equal in volume per second (or unit of time) with the stream of liquid in the spouting column at the base thereof, this base being at level 8^a ; also, to effect the de-aeration and energy-conversion simultaneously.

It will now be evident that the primary airlift of an air-lift pair, comprises means for laterally enclosing the uptake stream, or column of aerated liquid (when this airlift is operated with a submergence normal thereto) throughout the entire height of this stream or column, this height including an upper-end portion or zone which begins at the upper end of said uptake pipe, B, and extends up to the point where de-aeration is accomplished and upward movement of the liquid ceases. In this zone, the liquid gradually separates from the air, and is laterally transferred and formed into a new and different stream which consists of liquid flowing downwardly by the force of gravity, and thus constitutes a counter-flow stream. And this counter-flow stream after passing down to a position where the liquid thereof is substantially free from contact with, or the effects of the up-spouting stream (from pipe B), may then be said to pass through the port P and enter the submergence column, D, as a resisted sub-surface current, since this stream enters below the upper surface of the liquid submergence column, and is thus resisted by a force resulting from the head of such column, this head being normally of a height between-lines 8^b and 8^d , Fig. 4.

Thus, in the manner described in connection with Fig. 4, the kinetic-energy, or "vis viva," of the spouting-column becomes converted into a pressure which reacts downwardly for transmission by way of a fluid connection below said level 8^a , and to a next following airlift. This reaction-pressure, which may also be designated as the conversion-pressure,—is thus transmitted as an increment of head, which is so applied, and this in such a direction, as to augment the normal head of the submergence column of another airlift-member of the system.

The height to which, in practice, said spouting column will ascend within the de-aeration tube (or tubular chamber) as K, Fig. 4, will be through such a distance (disregarding friction) as will absorb, or represent, the amount of kinetic energy possessed

by, or residing in, the aerated fluid at the time this passes above the said level 8^a . Thus said energy, or "vis viva," becomes converted, and utilized in the production of a pressure which closely corresponds with the downwardly acting force or weight, of the spouting column, this force constituting a reaction-pressure as already explained.

Because of this effective utilization of said kinetic energy, it now becomes economical to provide, (in said primary airlift of the pair) for the use therein of such a volume of air in proportion to the volume of liquid taken in at the inlet N^1 (Fig. 3), and for supplying this air at such a pressure as will produce a relatively rapid upflow in the uptake pipe B, and thus (according to a well-known principle) minimize the loss of power resulting from the upward flotation, or "slippage," of the air in the liquid during the passage thereof upwardly from said nozzle or jet N, to the discharge level at 8^a , while correspondingly increasing the quantity of said energy as discharged in and with the spouting column.

The total "head," which, in the primary uptake column, is functionally effective (for determining the height of the submergence in the secondary airlift) includes the entire height of fluid, from the lower end at the intake level at 7^a (Fig. 3), up to the top of the spouting column. Thus the weight or pressure which as a resistance has to be overcome by the submergence of the primary airlift, consists of the fluid in pipe B plus the additional weight of fluid in the spouting column within the de-aeration tube, K. In this total uptake head, the fluid, after being elevated by the combined action of aeration and the submergence, is not discharged from the upper end of said uplift distance, but is drawn off at a point (at a "sub-surface" position) intermediate to the submergence level and the top level of the uptake column. And, in connection with a final de-aeration of the liquid, the air and the liquid,—instead of being discharged together in the ordinary way,—are now discharged separately, the air being released free from pressure (except the atmospheric pressure) and the liquid being drawn off de-aerated and under a substantial amount of pressure in excess of atmospheric pressure.

For more fully explaining the complex relations, and the methods of coaction, of the energy-converters, K, and for further illustrating the principles and the governing function thereof, reference is made to the series of diagram, and small-scale, views, Figs. 4^a to 4^d , inclusive, supplemental to Fig. 4. In each of these supplemental views, the said apparatus is assumed to have the same detail construction and arrangement as already described in connection

with Fig. 4, so that the several structural details thereof (so far as here shown) may be recognized without being here all designated by reference characters, nor again particularly described.

In Fig. 4^a, it is assumed that the apparatus is operating in a uniform or "balanced" manner; that is, the discharge of liquid upwardly from pipe B (arrow r^4) corresponds in volume with the down-flow of liquid in submergence-column D (arrows r^{14}) at a point below the level of the transfer-pipe, or conduit, P. Under this condition, the stream-flow from member K into column D, may be represented by arrows r^{12} , r^{14} , of which the latter, r^{14} , turns down into column D for thereby indicating the course of said flowage.

It is also assumed, in Fig. 4^a, that the spouting-column-head extends up to line 8^b (this line representing atmospheric pressure), and the super-head resulting therefrom is also here shown positioned above the path of main-stream flowage, and as extending in column D, up to the same line, 8^b; this super-head, S¹, is also indicated by shading just below, and extends up to, said line 8^b, and is now normally stationary. If, now, the submergence height in column D, normal to uptake pipe B,—when this discharges at line 8^a,—be considered as coming up to said line 8^a, then it is seen that the weight of super-head S¹ is supported above and pressing upon down-flowing stream S, in a manner clearly indicated by the opposing arrows r^{15} and r^{16} , which indicates, respectively, the upward resistance (arrow r^{15}), and the downward pressure, or weight, (arrow r^{16}), of super-head S¹. Thus, in Fig. 4^a, the stream flowing through conduit P enters column D under a super-atmospheric pressure equal to atmospheric pressure plus a pressure represented by the height of super-head S¹, measured upwardly from said conduit P.

In Fig. 4^b, the operations in member K, and the supplying therefrom of liquid to column D, are assumed to be the same as above described in connection with Fig. 4^a, excepting that the down-flow of the liquid submergence-column S has been accelerated to the extent of taking the same quantity through conduit P and also drawing down some liquid from the super-head,—here designated by S²,—until this super-head has been lowered from said line 8^b down to the level 8^{b'}; this head-lowering movement is here indicated by arrow r^{17} . An immediate and normal effect of thus lowering said super-head is to reduce the pressure-resistance to the described stream-flow through conduit P; and, if this reduction should be continued for more than a relatively momentary period, the spouting-head height, in converter K, would be lowered by an in-

creasing rate of the flowage therefrom and into said conduit P; this action, however, would tend to relieve the resistance to the stream up-flowing from pipe B, whereupon this stream normally would increase (especially by a quickly following expansion of the air-content thereof), and thus supply more liquid through conduit P, thereby tending to produce a reactionary movement for restoring the depleted super-head S². Thus Fig. 4^b illustrates, by comparison with Fig. 4^a, one of the more direct and constantly occurring of the inter-regulative functions. Such an initial lowering (or raising) of the surface level of the submergence super-head as above described, may readily occur in practice from various causes; as, for instance, from a stopping up of one or more holes in the liquid-aeration means, or as a result of some abnormal but temporary action in one of the airlift-members of a series of them. One such cause, usually quite temporary, may be an unusual degree of coalescence and the excessive rate of slippage consequent thereto.

In Fig. 4^c, said reactionary movement,—for restoring super-head S²,—is represented as having taken place. Assuming that the spouting-column (arrow r^4) has a pressure-head extending up to line 8^b, that, at the beginning, the super-head corresponds with S², Fig. 4^b, and that the down-flow velocity of the stream (arrow r^{14}) in column D has been somewhat reduced, then the flow through conduit P naturally divides, the main portion,—as before,—flowing down (arrow r^{14}) into column D, while a smaller portion flows upwardly (arrow r^{18}) to re-supply the submergence super-head, here designated by S³. In this manner, the lowered head, S², of Fig. 4^b, is gradually (usually rapidly) raised from said line 8^{b'} up to line 8^b,—as in Fig. 4^a,—and, under the action of the forces and inertias then appertaining to the apparatus and the streams therein, the level of this super-head, S³, will normally be carried up to a higher level, here indicated by line 8^{b''}. At this height, 8^{b''}, the added weight tends to again accelerate the down-flow velocity of the submergence stream (arrow r^{14}), and thereby again draw down the super-head level toward line 8^b, thereby restoring the status represented in Fig. 4^a, and already described. Thus the described range of successive heads, from line 8^{b'} to line 8^{b''}, may be said to constitute an "oscillation" in the operation of the apparatus comprising the energy-converter, K, and the upper portions of the columns B and D directly associated therewith, including the upper-end portion of column D which is the super-head container.

In practice, of course, the vertical extent of said oscillations necessarily fluctuates,

and these oscillations also occur with a variable frequency, depending largely upon the coaction therewith of operations simultaneously occurring in more remote portions of the system. Also, it will now be evident, the rate or rapidity of said action or movement for the restoration in height of a lowered supplemental head, as S^2 , depends in part upon the relative cross-sectional area of column D, so that by making this member somewhat larger than tube B, said rate of head-restoring action may be regulated, (within such limits as may be found desirable, in any particular instance), for inaugurating an acceleration of upflow in pipe B (by decreasing the column-head-pressure resistance thereto) at a moment,—or instant,—slightly before said process of head-restoration can normally be completed. This over-lapping of the said two functional and successive but distinct operations, is deemed to be desirable as tending to restrain a too great, or a too rapid, lowering of the effective head of the spouting column while assisting this column by a raising thereof, (by a transference of liquid and pressure), and thus continue to completion the raising of said lowered submergence head up to the full normal height thereof.

Thus the apparatus when organized and arranged as set forth, provides for a highly sensitive mode of interaction which operates as a quick-acting governor, and thereby provides for limiting the oscillations of flowage, and of heads and pressures, in a most effective manner. And the apparatus may be said to be also organized for regulating an intervening governing action by means of a supplemental-head chamber connected for direct coaction with the spouting-head during a time-interval following a change of flow in one uptake column, and prior to a resultant but in point of time, later and responsive uptake flow in the other said column, for thereby reestablishing without violent agitation, a balance of and between the operations therein.

Thus, in the time between an initial acceleration of upflow in column D, and a corresponding or ultimately-resulting increase of upflow velocity in pipe B, there has been an intervening governing-action consisting in the instant lowering of said head S^1 , followed at once by a partial restoration thereof. Thus said initial lowering of head S^1 , and the inaugurating of the restorative operation therefor, may be said to be preliminary to, and in point of time to functionally precede, the beginning of the acceleration of flow in pipe B for producing a newly determined balance as between the flowage in columns B and D.

A further feature of this series-system relates to means,—appurtenant to the primary airlift and the submergence container, or

column, of a secondary airlift,—proportioned for receiving and de-aerating the aerated liquid of said spouting column and for then distributing this liquid, each of these operations being continuous during the operation of the airlift pair. Said distribution is effected in a peculiar manner, being delivered (from time to time as required) in variable relative quantities, or proportions,—according to inequalities in the operation of the two airlifts,—in part to the upper end of said main submergence head (this end being at line 5^a, Fig. 4), and in part to the lower end, (at line 5^a, Fig. 4^c), of the supplemental submergence head, (as S^1 , Fig. 4^a) which extends upwardly from said main submergence head.

This interactive operation of two said airlifts under said variable distribution of liquid from the spouting-column, operates in connection with the described oscillation of flowage and pressure naturally occurring in the uptake pipes and conduits, as a factor in that joint operation of the airlift pair whereby a non-normal operation whether arising in one or the other of the two airlifts, is transmitted and counteracted or balanced, for thereby and at once re-stabilizing a normal operation of the system following the occurrence therein of many material inequalities in the operation of the two airlifts.

An important feature and advantage of,—and one which further distinguishes,—this uni-flow multi-stage system, consists in its capacity, on being subjected to certain irregularities as regards the air-supply and other conditions, for operating temporarily in a reverse-to-normal manner, and for then automatically starting, or resuming (as the case may be) its normal and forwardly-acting mode of operation. For instance, in practice,—especially in certain mining regions having workings difficult of access,—it has now become commercially important sometimes to supply the air through very extended pipe-lines from compressors located in valleys far below and where water-power is available for use in compressing the air by steam-power.

In such pipe-lines, however,—even when these lines are quite moderate in length,—water is liable to collect at one or more points therein,—from condensation or otherwise,—and be carried forward in a violent and oscillating manner with the result of making the air-supply and its pressure fluctuate extremely at the nozzles of the air-lift system. Some water, in such an instance, may be carried forward to one nozzle and for the moment completely block the operation thereof, while, at the same moment, air may be forced through one or more other nozzles under an excess pressure, and thereby force air backwardly (through a lower col-

umns-connection) and thence upwardly into a submergence column.

This reverse-to-normal and temporary mode of operation, is briefly illustrated,—
 5 but only in a diagrammatic manner,—in Fig. 4^d. In this view, the liquid stream in column D is indicated (arrow r^{19}) as having been reversed, and as having been driven up (arrow r^{20}) to form a highly elevated pressure-head, S^4 , which serves to temporarily
 10 store up a considerable quantity of liquid, while applying a heavy resistant pressure at the level of conduit P. When said head S^4 has been raised high enough to fully resist the normal flow (arrow r^{12} , Fig. 4^a) from the member K, then a portion of the liquid flowing up in column D (at arrow r^{19}), will naturally be diverted (arrow r^{21}), and pass
 15 through conduit P, flow (arrows r^{22}) up into the de-aerating chamber of converter K, and thereby reach a point so far above line 8^b , as to press back (see arrow r^{23}) the normally rising stream (arrow r^4) in uptake pipe, B, and thus for a time stop the operation of
 20 this pipe as a liquid-supplying means,—this being here indicated by the opposing heads of arrows r^4 and r^{23} , within said pipe B. On this status of the flowages being continued for a time, the normal up-flow in pipe
 25 B may be changed to a down-flow, and thereby deliver liquid (supplied upwardly through column D) into the submergence column of pipe B. Thus, said back-flow, if sufficiently continued or extensive, tends to
 30 conserve the contents so displaced, by shifting the same backwardly in the system, stage by stage, as far as may be required for the storing thereof, and thereby avoids a reduction of the liquid content of the system as a
 35 whole.

When there occurs a sudden back-flow of excess-pressure air, (as elsewhere herein explained) this back-flow normally operates to over-aerate the lower-end portion, and
 40 thereby raise the whole quantity of the liquid of said submergence column, but only to a height much less than the same quantity of air would normally raise the liquid in an uptake column, since the cross-sectional area of the submergence column (as
 45 herein illustrated) is made considerably greater than the cross-sectional area of the uptake column. This feature, and relationship, is deemed to be particularly important, since it favors a backward flow of
 50 liquid through successive air-lift system-members, and thereby,—through the maintenance of a full supply for these members,—prepares them for automatically
 55 starting to act in a forward direction at once on the air-supply subsiding to a normal pressure extending equally to all the aeration devices of the series.

Thus the present system under normal conditions operates to forwardly actuate

the stream by the uni-flow method, and under the described occasional and abnormal conditions, operates backwardly in a manner which, besides conserving the liquid contents, by a storing thereof, enables the
 60 system to immediately resume its normal operation on a restoration of a normal air-supply. Thus it may be said that the several air-lift system-members are not only
 65 inter-regulative as regards their forwardly-acting functions, but also are inter-acting and inter-regulative as regards and during a temporary reversal of their normal mode of action, for thereby making the system
 70 self-starting and self-regulating under a wide range and variety of opposing conditions which otherwise would normally halt or defeat the operation thereof.

An analogous situation as may arise from the described use of said pipe-line air-supply, may also arise in some instances from
 75 other causes, as for instance, when the compressors are located near the air-lift system, and especially when, in this arrangement, the compressor is actuated electrically by conductors bringing the electric
 80 current from distant power plants. In the latter case, as is well-known, the power lines are subject to surging effects, thereby varying the action of the motors and compressor; and this, in turn, may suddenly and
 85 materially (even if only temporarily) change the effective relation of air-supply to the normal requirements of the air-lift-system. Such variations may frequently be
 90 sufficient, in practice, to disarrange the operation of a multi-stage air-lift, unless overcome instantly by counter-acting forces; this is accomplished in the present system
 95 by the described capacity thereof for a reverse-to-normal mode of action, and for the automatic resuming of a normal forwardly-acting mode of action, and by having the described inter-regulative function effective
 100 under each of these relatively reverse modes of action.

In this connection, it should also be pointed out, that the continuity of operation may be disturbed, or in some instances
 105 suspended, as the result of accidental causes, especially in mines and quarries, and in certain industrial plants. For instance, the water-supply may be changed in character, or in specific gravity, by the incorporation therein of dust or silt, or it may
 110 become impregnated with gas, or gas-forming materials, in one (or a few) of the submergence-columns; this latter accident might so reduce the submergence-effect at
 115 one or more points, as to prevent the coacting aeration from producing a forward flowage of the liquid in the system. Also, especially in certain "wet" mines, one of the columns may be suddenly flooded from
 120 above, thereby over-charging a submergence

column, or an energy-converter, or both, to the extent of halting the operation of the entire apparatus. In these and other ways, either a "single" air-lift or a series system, may be stopped; but in the present system, this has the unusual capacity, as already explained, of normally being self-righting, and self-restarting upon the subsidence or removal of such an interrupting cause, and of thus resuming operation in a normal and self-continuing manner.

A further feature of improvement in the airlift pair, and in the operation thereof, is more clearly indicated in Fig. 3, this view being analogous (in the main) to Fig. 2. Assuming the apparatus to be operating regularly, and with the supplemental submergence head maintained at rest,—as described in connection with Fig. 4^a,—then, it is evident the upflow stream into secondary uptake pipe B² must be just equal in quantity per unit of time, to the flow through port P² into the main submergence container, or column D². If, now, the rate of flowage of said stream into pipe B², should be accelerated as a result of a change of action in pipe B²,—as may readily and often occur for reasons already stated,—this instant increase would naturally have the effect (at least momentarily) of reducing the effective pressure in the entire length of such stream, and would thus instantly decrease the opposition of this stream and its pressure to a more rapid inflow through said port P². Thus an increase of flowage velocity in one pipe instantly and normally decreases the resistance to the stream flowing thereinto; and this result is deemed to be one of the most important of the interactive functions of any pair of coacting airlifts.

The said intermediate uptake-column, B², has a special relation to the next preceding and to the next following airlifts, (see Fig. 3) in that the up-flowing stream in B² is not only elastic, but is coactive between, and subject to the constant restraint of, two non-aerated liquid down-flowing streams each of which is in communication with said elastic stream at positions therein which are under the pressure of a constant head of liquid. Thus an oscillation occurring in said elastic stream is met, and normally partially checked, by the inertia-resistance of a non-aerated stream, whether such oscillation tends to act forwardly or backwardly, or in both of the directions at once. Also, of these resistances, the greater one is in a backward, and the smaller one is in a forward, direction; and these inertia resistances are coactive with each other through said elastic stream being intermediate thereto. At the same time said down-flowing stream (in column D³), is coactive with and intermediate to the two upflowing

elastic streams in columns B² and B³, so that in the said coaction of the stream in column D² with the elastic stream in column B², this stream in column D³ so acts after being modified in its (otherwise normal) action by its said coaction with the elastic stream in column B³. Thus the total coaction as regards either said stream, is of a composite nature, and comprises coactive effects appurtenant to several and different pluralities of column streams, which operate concurrently.

Thus it may be said that in the more extended developments of the present invention, there is a multi-lift system of airlift elements connected for uni-flow operation, and comprising successive (two or more) of the column-pairs, through which the liquid stream is not only continuous, but is subjected to the controlling effect,—at each said down-turn portion thereof,—of a constantly-acting super-head pressure. These column-pairs, as B¹ and D², or B² and D³ (Fig. 2 or Fig. 3), may thus be said each to be top-connected by an economizer-regulator, since the "converter", as K, economizes the residual energy of the upflowing aerated stream, and thus, also, is coactive for providing the "head" required for use in effecting the interactive regulation, and thus effect the auto-governing.

A further and special purpose of said upward extensions of the columns D, is to provide a head of liquid which is not located directly in the path of the stream, (see Fig. 4^a), but is so joined to and above such stream-path that this head of liquid constitutes a sufficient reserve or supply to which liquid may be added from below, (by an under-feed method), and from which liquid may be withdrawn, in and for the interactive regulation of the successive airlift elements, and without materially affecting either the continuity or flowage of the liquid in its said path nor as a unifold stream, nor the plus-atmospheric pressure under which this flowage takes place in said down-turn portions thereof. Thus the stream considered as a whole,—and on the occurrence of variations in the operation thereof,—may have applied instantly thereto, a force and a liquid-supply (drawn from one or more of said reserve heads) tending to supplement or to counteract such stream-variations and thereby restore a regulated and normal flow.

A further feature of the inter-regulative functioning, relates to the effects produced on the inflow of air through nozzles N, by the varying momentums and inertias of the down-flow streams in columns D, whereby, at certain moments and under the varying conditions of the connected up-flow streams in columns B, the rate of the air supplied through one nozzle may be changed for the moment and in an automatic manner, and

thus become directly co-active in relation to the governing of the operation of the system. In an extended multi-stage system, those air-flowage variations may occur in one portion of the series to increase the air-supply of one uptake-stream, while in another portion of the same series of airlifts, the supply of air through the nozzle of another uptake column may be decreased; or, such increases,—or decreases, as the case may be,—may occur simultaneously at such different positions in the series.

For instance, when there is an increase of pressure in column D^2 (see Figs. 2 and 3) while the pressure in column D^3 remains stationary (for the moment), the normal effect is to apply more pressure to the lower end of the stream entering column B^2 , and thereby somewhat increase the resistance to the in-flow of air through nozzle N^2 . And, should the pressure-resistance in column D^3 be suddenly reduced, while no increase of pressure should then occur in column D^2 , a normal result would be to permit, for the moment, an increased flow of air through said nozzle N^2 , and thereby, also, aid (both directly and indirectly) in restoring a balanced operation of the whole system. Such changes, occurring at any point in the system, tend instantly on beginning, to modify the pressure or rate of action at adjacent points and thereby counteract the otherwise disturbing effect of such a change from the normal balance, and thereby aid in securing an interactive regulation as a result of the reciprocal and peculiar coaction elsewhere herein more fully described.

Since, as above pointed out, a variation from a uniformity of functioning at any one of said points of the regulative action, operates by transmission of the effect (of such variation) in a forwardly and also in a backward direction,—and this at the same instant,—therefore, when two such variations occur simultaneously at successive positions, respectively, in the system, all that portion of the system which is intermediate to the said locations of the variations, is subjected to a plurality of the transmitted regulative influences, or effects, with the result that the complete regulation,—when any is needed at any place or instant,—is of a complex nature, and is accomplished in such a prompt and effective manner as to involve only a relatively small change in any one of the super-head column-increments. And, in such a complex regulative operation, or functioning, when a variation of action occurs in one uptake-column (except the primary one), this action is transmitted, or reacts, through the directly coacting submergence column and thus tends to reversely modify the super-head or column-increment which serves as the supply-means in

the regulation of the pressure-head of this submergence column.

It will now be evident how the described graduation of the transmitted regulative effects, from a variation-in-action occurring initially at a position above midway in an extended system,—especially when the number of airlift-members exceeds three or four,—has the important feature of gradually reducing the extent of the interaction in passing through such a series, until the total effect becomes distributed in a manner tending to produce a restoration of a completely balanced action throughout the series, including the airlift-member in which the variation first arose. Another valuable result is that when two (or any plurality of) such variations occur simultaneously, or nearly so, at relatively distant points,—(or originate in non-contiguous airlift-members), the resultant series of transmitted variations may blend together (as transmitted to and appearing at intermediate points) and thus be more quickly neutralized, and become coactive more quickly and fully in effecting the required balancing of the operations of each airlift-member, and of the system as a whole. And this equalization of said variations and transmitted effects is further favored by the described delaying (owing to the time intervals required therefor) of the successive said effects, so that any plurality of such initial variations-of-action become rapidly restored by the described interaction, this normally proceeding both forwardly and backwardly in the series of airlift-members, from each of said initial variations.

Owing to the described transmission,—forwardly and backwardly in a system comprising two or more of the airlift-members,—of the said initial variations-of-action, and of the said regulative actions for counteracting the same, it will be evident that each of said airlift-members shares in the operation and functioning of the member or members which are next thereto in the system, so that in the connected series of such members, none of them can be said to operate alone, or as an independent, or single, airlift. Thus the system has the character of a unitary apparatus, and as one arranged for performing and effecting a single operation and result, this being to elevate the liquid through the entire distance required and by a uni-flow stream having therein no points of disconnection, regardless of the number of times,—during such total lift,—this stream shall be subjected to the forwardly-impelling pressures, or to the successive aerations and de-aerations whereby said pressures (or submergence-effects) may be produced and applied thereto. For these purposes, the successive

means,—as for instance, the conduit formations,—for aeration and de-aeration of the liquid should be so placed and proportioned that the aggregate force thus exerted on the stream will correspond in power to the height the liquid is to be lifted in passing from the intake point up to the point of final stream discharge.

In ordinary practice, as is well-known, the kinetic effect of a given submergence-head in pushing up an aerated liquid column in a connected uptake pipe, is directly affected by any variation in the resistance to up-flow of said aerated column. This resistance, as also well-known, ordinarily and normally varies in a fluctuating manner, so that the resultant uptake flowage may be described as normally having a wave-like action, and this result may occur, or accrue, with a varying degree of force, and with a variable periodicity. One cause of those variations is understood to arise from a fluctuation in the rate of coalescence, and the consequent enlargement of the size of the air-bubbles in the up-flowing aerated column so that any abnormal increase of the coalescence, even momentarily, thereby increases the velocity of the upflow, or "floatation" rate, of the bubbles in and relatively to the upflowing liquid content of the aerated column.

These wave-like variations may occur, in the present multi-stage system, simultaneously in two or more of the uptake-columns, or they may occur therein in alternation, so that two of said kinetic resistances may occur in two successive uptake-columns at the same moment and thereby apply to the uni-flow stream a double resistance-effect; and, at another moment, an increased resistance may occur in one said column simultaneously with a decreased resistance occurring in another said column. Thus, in the operation of the system as a whole, one said action may for the moment either counterbalance or supplement the other, so that these actions may be said to become coactive each with the other.

A well-known objection to the use of uptake columns of great length, arises from the large ratio of increase in the volume of a bubble in passing upward therein, due to the great range of pressure to which such bubble is thus subjected, and since the slippage also increases with the increase of diameter of the bubbles, the loss normally arising from this cause is in itself a considerable one, besides causing an increased amount of coalescence. This latter result is often a serious one, the frequent but irregular combining of two or more bubbles into one, operates unduly to increase the volume of a bubble and hence to further increase the rate of the slippage, as well as to accelerate the velocity of the up-

flowing stream as the air content thereof is increased in volume as it approaches the upper end of the uptake column.

In view of those conditions, it is one object of the present invention to provide an apparatus especially adapted for economical operation when using relatively low heights of "submergence" and "lift", and thereby minimize said range of pressures and the extent of the volumetric change in size of bubbles, and thus restrict the increase in the rate of slippage thereof while the bubbles are passing through the entire length (height) of the uptake column. By using only relatively low lifts, and a sufficient number, or series, of these multi-lift stages for raising the liquid to a given elevation, not only are the pressure changes brought within a smaller range, and the slippage reduced in quantity and velocity, but a relatively greater number of spouting-column energy-conversions are obtained in a given height.

This feature and advantage is deemed to be of special importance, since in a lower-pressure system the aggregate of surface-contact between the air-content and the water-content of the upflowing column is much greater in proportion to the relative quantity therein of free-air, so that a relatively large ratio of heat transference,—within practicable limits,—can now be economically obtained, and this in connection with a minimizing of the well-known initial loss of heat due to the described air-compression and radiation.

Usually the heat developed in the air-supply by its compression is necessarily lost by radiation before this air can be incorporated (in the form of bubbles) into the lower end of the aerated up-take column, so that, at this lower point (or level), the air and water are of substantially the same temperature. During the movement of the bubbles upwardly from said lower level, the air thereof continually becomes cooler by reason of their expansion, and this loss of heat is gradually and largely compensated by the transference by conduction of heat from the water to the air by means of said surface-contact of the bubbles with the water.

These combined gains and advantages are also obtained, in the present system, in connection with a further advantage and result which is deemed to be of special importance as regards the inter-regulative function peculiar to this system, and whereby a complete and constant regulation is automatically obtained without the aid of any mechanically operable devices, and without any discharging of un-utilized air-pressure. As already pointed out, (see Fig. 3 and the description thereof), a series of uptake pipes and down-flow conduits are

arranged in alternation and are laterally and sub-surface connected for the uni-flow operation, and (while the system is operating) are filled, respectively, by elastic up-flowing and non-elastic down-flowing streams of fluid. Now, it will be evident that the weights, and the momentums and inertias of these streams will be quantitatively less in the said shorter lifts, so that by and during the described inter-action thereof, these fluid streams will be more sensitive in action, and thus much more prompt in their response to transmitted impulses, in the shorter lifts as compared with the action and response which would occur with the heavier and hence less sensitive columns of the greater lengths.

Thus, it may be said that the means and features which produce in a cumulative manner, said combined gains resulting from conversion of spouting-column energy, from reduction of slippage and coalescence losses, and from the said heat-loss compensations, are not only cooperative, but together constitute a means, or agency, for utilizing said features and cumulative results in a way to obtain a highly sensitive and more prompt and effective operation of the inter-regulative function of this system considered as one continuous and unitary air-lifting apparatus operating by the uni-flow method.

When a plurality of single airlifts are arranged in a series, each of the airlifts in such an organization,—similarly as when it is used singly,—may be distinguished, or described, as comprising in the combination two columns, or pipes, one being the "submergence-column", and the other being the "uptake column", these two columns being of shorter and longer relative lengths, respectively, and being joined at their lower ends for supplying liquid from the submergence-column into the lower part of the longer uptake-column, and the latter being provided (as in usual practice) with an aeration means. For instance, in the ascending series system herein illustrated in Fig. 3 the column D^2 is a "submergence" column, and is also a conduit for a down-flowing stream. At its lower end said column D^2 is connected by a conduit E^2 with the lower end of the longer "uptake" column B^2 , which, (being for the upflowing stream) is shown provided at N^2 with liquid-aeration means, thereby forming one "airlift",—or air-lift unit,—but only a single one. Similarly, the columns designated by D^3 and B^3 , are the "submergence" and "uptake" columns, respectively, of the next following single airlift-unit, comprised in the same series, or system. Thus, in the said series of columns, the two kinds are placed in alternation, and thus are arranged

in two series of coactive and successive pairs. In one series each pair consists of an airlift-unit, and comprises a submergence column as the first member thereof, and an uptake column as the second member thereof, (these two members being bottom-connected), and the path of flowage being through an "up-turn", and from the lower end of said first member and into the lower part of said second member,—that is, in a direction from "submergence" to "uptake".

For the purposes of the present invention, however, the said series of alternating columns are further distinguished by an arrangement of these columns into coactive pairs of single columns, or column-pairs, having a different and peculiar relation, and in which the order, or sequence, of the two columns in a pair of them, is reversed. Thus, as here considered, the uptake column B^1 and submergence column D^2 , constitute one pair, of which said uptake column is the first member, and supplies the said submergence column, which is now the second member of such a pair. Similarly, the uptake column B^2 and the next following submergence-column, D^3 , constitute the first and second members, respectively, of the next following and more elevated column-pair of said series. One of these pairs, it will be noted, while not itself constituting an "airlift", comprises the second column of one airlift and the first column of a next following airlift, these two columnar members being top-connected, and the path of flowage being through a "down-turn" and from said first member into said second member,—that is, in a direction from "uptake" to "submergence".

Thus the two kinds of columns being arranged in the described alternation, constitute a plurality of bottom connected pairs of columns in which each pair comprises one column of each said kind; and the same arrangement of alternating columns constitutes another plurality of pairs which are top-connected, and in which, also, each pair comprises one column of each said kind. Thus, the alternating series of columns may be said (when organized as set forth) to constitute a dual system, this comprising column-pairs arranged in two series, and having the pairs of each series mechanically and functionally complementary to the pairs of the other series. Accordingly, the series of three single airlifts shown in Fig. 3 comprises two of the bottom-connected pairs, and two of the top-connected pairs, while these four pairs comprise five single columns. And, the two up-turn positions, at E^2 and E^3 , (Fig. 3) and also the two down-turn positions, at P^1 and P^2 , (Fig. 2) are all intermediate to, and functionally coactive with, the initial (or

primary) liquid-receiving uptake column, B¹, and the terminal, or discharging uptake column, B³.

These several features and relationships are deemed to be important in connection with the establishing and maintenance of a "uni-flow" stream of the liquid to be elevated by this airlift system. This kind of a liquid stream is indicated in Fig. 3 by the heavily shaded lines of arrows, r^a , r^b , r^c , in pipes B¹, B² and B³, respectively. Entering the uptake B¹ at N¹, the liquid flows up to the top portion of this column, and thence passes by a down-turn, at r^3 , and through conduit P¹, into the down-flow column D²; next, the liquid flows down to the up-turn at E² and then enters the second uptake column B², which leads the stream to the second down-turn at P². Similarly the flow continues down the submergence column D³, through the up-turn at E³ into the uptake column B³, and is finally discharged at the upper end of this column. And, it is one object of the present improvements, to provide for making the liquid to flow from said inlet at N¹ to said final outlet in a stream which is not only continues but is maintained as, and in the form of, one uni-flow main-stream throughout its path of flowage.

For effecting said object, the present uniflow system is herein shown arranged and provided with means whereby to subject the liquid stream at two or more successive down-turn portions thereof, to the pressure of a head superposed upon those stream portions in such manner as to maintain upon the stream a plus-atmospheric pressure throughout the entire course, or path of flowage, thereof, including said down-turn portions.

For this purpose, said top-connected pairs of columns may be provided,—preferably in the manner elsewhere herein more fully explained,—with an upward extension for each column of such pair, these extensions being connected in series, and together forming an apparatus which, as to its broader phase and more generic character is designated as an "economizer-regulator."

And said apparatus, (for the reasons herein explained) is shown provided with channel and chamber spaces connecting and arranged for de-aerating the liquid and for economizing the kinetic-energy thereof, and serves to transmit the stream while this is under the super-atmospheric pressure. Thus, it will be seen that said economizer-regulator is proportioned, positioned and operable as a means for maintaining in each said extension, a super-head of liquid that is superposed above and upon a down turn portion of said continuous stream, (see Fig. 4^a, and description thereof), and for obtaining and maintaining that superhead, and the superposed pressure thereof, by a

peculiar and effective inter-regulative co-action.

Referring again to Fig. 3, it will be seen that an important feature of this multi-stage uniflow system when comprising three air-lift members, is that one uptake column, as B², is intermediate to, and directly coactive with, two down-flow columns. All the up-flow streams, in the several uptake columns, respectively, are aerated streams, while those in said down-flow columns necessarily are de-aerated streams. Now, such an aerated stream is longitudinally elastic, and sensitive to variations in the actuating and resistant forces to which it may be subjected; and, these forces include, of course, the energy and the inertia of the said non-aerated down-flow streams in columns D² and D³. Therefore, while this three-member system is in operation, said aerated and elastic up-flow stream in column B² is intermediate to, and is directly coactive with two non-aerated down-flow streams of which the one next preceding (in column D²) is coactive with a preceding elastic up-flow stream, (in column B¹) and the other of which (in column D³) is coactive (but in a reverse manner) with a next following elastic up-flow stream, as B³. Thus, as will now be obvious, this three-member system, or combination, involves a peculiar coactive and inter-regulative functioning which is more extended and also more complex than occurs in the system when this comprises less than three of the air-lift members.

One of the leading features of the present multi-stage air-lifting system, relates to a combination wherein two of the combined economizers and governors are located at successive positions and elevations, respectively, and in their operation are coactively connected with each other by sub-surface streams, and through a pair of columns which comprises one down-flow liquid-submergence-column non-aerated and under super-head pressure, and comprises one uptake column bottom-connected with and supplied with liquid from said submergence-column, and having therein a longitudinally-elastic aerated fluid column through which liquid is supplied from the first and lower said combined economizer and governor and delivered into the said second and more elevated one of them. Thus, in the auto-governing functioning as effected in this combination, said second and more elevated economizer-governor, as "K," may be said to operate in a resistant manner against said first and lower economizer-governor, by force transmitted, first, through an intervening elastic column tending to yield under such resistant action, and, second, through a non-elastic liquid column (in said submergence column) having a resistant inertia, these two factors, of elasticity

and inertia, operating coactively (sometimes forwardly and at other times backwardly) to create a time-interval as between a transmitted impulse arising or developed in one said economizer-governor, and the time such impulse becomes effective on the other said economizer-governor. For the present purpose, such an impulse or force transmitted from any one of said members K, may be regarded as "arising" therein, although initially, and in part or wholly, it may have arisen at, or from a variable operation of, one or another of the aeration devices, N, and have been transmitted therefrom to the member, or members, K.

In this manner, and by the described means, the transmission of an impulse, or a regulative force or action, from one to another of the economizer-governors,—as, for instance, from K^1 to K^2 , or from K^2 to K^3 , or reversely;—while made rapidly is not instantaneous, since such a transmission of regulative action (or "pressure-effect") is necessarily made (whether in one direction or the other) through an up-flow stream having longitudinal elasticity, and which, in yielding under said force or impulse, involves a brief but effective time-interval. This mode of action as regards the transmission of a single said force or impulse, may occur as regards two such forces transmitted in opposite directions at the same instant. For instance, such a force arising, or accruing, in converter K^1 , and directed toward converter K^2 , may be substantially coincident with another one arising (or developed) in converter K^2 and directed toward converter K^1 , being thereby combined, or counteracted, one said force with or by the other; or, one such force may arise in converter K^1 at the same time another arises in converter K^3 , these forces being each directed toward converter K^2 , which thus sustains a double pressure-effect, and performs (for the moment) a double duty. Also, similar forces may arise in two next adjacent converters, as K^1 and K^2 , and both be directed toward converter K^3 , thereby tending to subject the latter, K^3 , to a plurality of the pressure-effects coming from the same direction at the same time; but this result is opposed by the described provision for the time-interval, which prevents the said forces from converters K^2 and K^1 from reaching converter K^3 at the same instant, but only in succession, since between K^2 and K^3 there is only one said elastic column,—as B^3 , Fig. 3,—whereas two of these columns intervene (and thus normally have successive times of action) between converters K^1 and K^3 . And, in a more extended development of this multi-stage system, pluralities of said energy-converters, or economizer-governors K, may coact,—and with varying degrees of energy,—with other pluralities

thereof which either precede or follow, in the series of airlift-members of the system. These explanations illustrate the extremely wide range of the coactive forces, or actions, which are transmitted, from time to time, through, or to and from, successive portions of the uni-flow stream while this is at all points of its flowage path under a super-atmospheric pressure sufficient for causing an effective transmission therein of said co-acting regulative impulses, forces and pressure-effects.

The regulative heights, or ratios, of the sum of lifts L^1 , L^2 , L^3 , and the sum of super-head heights h^1 , h^2 , h^3 , as represented in the diagram view Fig. 3, are illustrative of the principles and functions involved, and it is to be understood that in practice said ratios, or values, will be dependent,—as to their exact or preferable proportions,—upon the dimensions and normal rate of action of the several system components, and upon the structural character of their details, and also upon the air-supply and stream-velocities which are to be employed. And it is intended that when designing a multi-stage and uni-flow system comprising the present improvements, the elements and details thereof which are of an ordinary character, may be substantially in accordance with the proportions and data already recognized in this art as being good practice,—especially as regards strain-velocities, and the air-supply and its pressure,—for the quantity of work to be performed. This information, as regards features and details not peculiar to the present invention, is now so well-known in this field of engineering that it is deemed to be unnecessary to give herein a more particular account thereof.

In the foregoing description, and following a conventional practice, reference is sometimes made to the "operation" and functions, and to the "mode of action" and other features of members and devices which are parts of an apparatus that is, even while in use, wholly and constantly stationary. But it will be understood that in air-lifts the tubes and other structural components "operate" in conjunction with submergence-effect, and while the apparatus is supplied with streams of liquid and air under pressure, so that stationary parts may here be said to be "operable," and to "act" when thus supplied and under the forces then in action in connection therewith. since these stationary parts act by furnishing guidance and limitation, and by directing the movement and coaction of the flowing streams, and by regulating the application thereto of the actuating and resisting forces whereby the several described results are obtained.

The several improvements which are herein referred to or described, but which are not herein claimed, or which may not be

properly claimable in the present application, are regarded as being broadly within the scope and purview of the present invention, and are intended to constitute subject-matter in separate applications to be co-pending herewith. For instance, in the three-stage system as shown in Fig. 3, certain features thereof are intended so to be claimed, but are herein partially set forth for the reason that the present improvements as herein described and claimed are deemed to be particularly applicable to, and effective for use in, multi-stage systems comprising three, or more than three, of the described system-members, or air-lift units, especially when these have a "lift" and "submergence" less than usual, and are therefore operable by air of a relatively low pressure.

Having thus described my invention, it should be understood that there may be modifications thereof and variations therein without departing from the spirit of the invention, or exceeding the scope of the appended claims.

1. A multilift uniflow airlift system comprising, in combination, a first uptake column and a second uptake column in successive positions and at successive elevations, respectively; a submergence column intermediate to said uptake columns and at its upper end open by an outlet to atmosphere and at its lower end connected with and to supply liquid to said second uptake column, and having said upper end thereof extending above the height of a liquid-head and submergence-effect normal to said second uptake column, and means appurtenant to said submergence column and first uptake column and including a closed-in channel forming a portion of a sub-surface flowage-path for the uniflow stream, for deaerating within the first uptake column an aerated upflowing stream and transmitting this deaerated liquid into the submergence column at a position below said open upper end thereof and thereby form by an under-feed thereto a super-head column-increment located in the submergence column above the flowage-path of the uniflow stream.

2. A multilift uniflow airlift system comprising, in combination, a first uptake column provided with an energy-converter positioned above the discharge end of an uptake-tube thereof, and also comprising a second uptake column, these two uptake columns having aeration means and being located in successive positions in the system and at successive elevations, respectively; a submergence column intermediate to said uptake columns, and at its upper end open by an outlet to the atmosphere, and connecting at its lower end with the lower part of said second uptake column and having

its said open upper end forming a reserve-supply chamber; and a closed-in transmission channel in position and connected for transmitting an unaerated liquid as a sub-surface stream from a position below said converter of the first uptake column and into said submergence column at a point thereof below the level of said discharge end of said uptake-tube of the first uptake-column and thereby supply said chamber by an under-feed thereto with a reserve-supply of liquid having a plus-atmospheric pressure transmitted from said energy-converter through a subsurface stream.

3. A multilift uniflow airlift system comprising, in combination, a first uptake column provided with an energy-converter positioned above the discharge end of an uptake tube thereof, and also comprising a second uptake column, these two uptake columns having aeration means and being located in successive positions in the system and at successive elevations, respectively; a submergence column intermediate to said uptake columns and at its upper end open by an outlet to the atmosphere, and connecting at its lower end with the lower part of said second uptake column, and having its said open upper end forming a reserve-supply chamber; and a closed-in transmission channel forming a portion of a flowage-path for the uniflow stream, this channel being in position and connected for transmitting an unaerated liquid stream from a position below said converter of the first uptake column and into said submergence column at a point thereof below said reserve-supply chamber, and thereby supply said chamber by an under-feed thereto with a reserve-supply of liquid located between the flowage-path of the uniflow stream and said outlet to the atmosphere.

4. In an apparatus for elevating liquids in a uniflow stream and by the airlift method, in combination, a first airlift-member and a second airlift member located in successive positions and also at successive elevations, respectively, and connected for conjoint operation by a subsurface channel positioned for a down-turned stream-flow therein, each said airlift-member comprising an uptake-tube having aeration means at the lower part thereof, and the uptake-tube of said first airlift-member having at the upper end thereof a kinetic-energy converter in position, connected and arranged for forming a super-head column-increment, and for normally maintaining this super-head above the path of the liquid stream in said down-turn portion thereof, and said second airlift-member having a submergence column with its upper end in position and connected for receiving said column-increment as formed by said first airlift-member, and with its

lower part connected by an upturn with the aeration means and lower end of said uptake column of said second airlift-member.

5 In an apparatus for elevating liquids in a uniflow stream and by the airlift method, in combination, a first airlift-member and a second airlift-member located in successive positions and also at successive elevations, respectively, and connected for joint operation by a subsurface channel positioned for a down-turned stream-flow therein, each said airlift-member comprising an uptake-tube having aeration means at the lower part thereof and having at the upper end thereof a kinetic-energy converter in position, connected and arranged for forming a super-head column-increment, and for normally maintaining this superhead above the path of the liquid stream in a down-turn portion thereof, and said second airlift-member having a submergence-column with its upper end in position and connected for receiving said column-increment as formed by said first airlift-member, and with its lower part connected by an upturn with the aeration means and lower end of said uptake column of said second airlift-member, and thereby interactively connecting through said second uptake-tube, the kinetic-energy converter of said first airlift-member with the said kinetic-energy converter of the second airlift-member.

6. In an apparatus for elevating liquids in a uniflow stream and by the airlift method, in combination, a first airlift-member and a second airlift-member located in successive positions and also at successive elevations, respectively, and connected through a down-turn subsurface stream-path for conjoint operation, each said airlift-member being provided with an uptake-tube and aeration means therefor, and the uptake tube of said first airlift-member having at the upper end thereof a kinetic-energy converter which is in position, connected and arranged for forming a nonaerated super-head column-increment, and for normally maintaining this column-increment above the path of and as a pressure-load upon the said down-turn portion of the stream, said second airlift-member having a submergence column with its upper end of a height and connected for receiving said column-increment and having its lower end connected by an upturn with the lower end of said uptake tube of said second airlift-member, for thereby by means of a nonaerated liquid stream in said submergence column connected said nonaerated super-head column-increment with an aerated and elastic liquid stream up-flowing in said uptake-tube of the second airlift-member, for thereby modifying a flow-regulating action transmitted forward-

ly from said energy-converter and super-head column-increment.

7. In an apparatus for elevating liquids in a uniflow stream and by the airlift method, in combination, a first airlift-member and a second airlift-member located in successive positions and also at successive elevations, respectively, and connected through a down-turn subsurface stream-path for conjoint operation, each said airlift-member being provided with an uptake-tube having aeration means in the lower part thereof and having at the upper end thereof a kinetic-energy converter which is in position, connected and arranged for forming a nonaerated super-head column-increment, and for normally maintaining this column-increment above the path of and as a pressure-load upon the said down-turn portion of the stream, said second airlift-member having a submergence-column of a proportion, and with its upper end of a height and connected, for receiving said column-increment as an upper-end-portion above a nonaerated stream down-flowing therein, and having its lower end connected by an up-turn with the lower end of said uptake-tube of said second airlift-member for thereby by means of an aerated and elastic up-flowing stream in said second uptake-tube connecting said super-head column-increment of said second airlift-member with the nonaerated liquid stream in said submergence column, and thereby modify a flow-regulating action transmitted backwardly from said energy-converter of said second uptake-tube.

8. In a liquid-elevating system, the combination with a primary uptake column positioned and provided for initially receiving and aerating a stream of liquid upflowing in the lower part thereof and under an applied submergence-effect, of a laterally-enclosed and upwardly-extending spouting-column-receiving deaeration-channel constituting an upper portion of said uptake column and having a height greater than the height of a spouting-head of aerated liquid normal to said primary uptake column when this column is operating under the said applied submergence-effect; means including said spouting-column channel for deaerating the liquid of the spouting-column and simultaneously converting the kinetic-energy thereof into a super-head pressure, and for delivering the deaerated liquid downwardly in said channel in a counter-flow stream; and, means positioned and connected for delivering said counter-flow steam out of said uptake column while maintained under the super-head pressure produced by said energy-conversion in said spouting-column channel.

9. In a liquid-elevating system comprising a primary airlift-member and a second

airlift-member, in combination, a primary airlift-member having an uptake column positioned and provided for initially receiving and aerating a stream of liquid upflowing in the lower part thereof and under an applied submergence-effect; a laterally-enclosed and upwardly extending spouting-column-receiving deaeration-channel constituting an upper portion of said uptake column and having a height greater than the height of a spouting-head of aerated liquid normal to said primary uptake column when this column is operating under the said applied submergence-effect; and means including said spouting-column channel and in position and arranged for simultaneously deaerating the liquid of the spouting-column and converting the kinetic-energy thereof into a super-head pressure, and for transmitting this pressure and said deaerated liquid to the submergence column of a second airlift-member, and to a subsurface position therein.

10. In a liquid-elevating system comprising a primary airlift-member and a second airlift-member, the combination with a primary airlift-member having an uptake column positioned and provided for initially receiving and aerating a stream of liquid upflowing in the lower part thereof and under an applied submergence-effect, of a laterally-enclosed and upwardly-extending spouting-column-receiving deaeration-channel constituting an upper portion of said uptake column and having a height greater than the height of a spouting-head of aerated liquid normal to said primary uptake column when this column is operating under the said applied submergence-effect; means including said spouting-column channel for deaerating the liquid of the spouting-column and simultaneously converting the kinetic-energy thereof into a super-head pressure; and means including the outlet channel of a three-channel junction and in position and connected for transmitting said super-head pressure to the submergence column of a second airlift-member at a subsurface position therein and by a stream flowing under said super-head pressure, said means being also proportioned and arranged for maintaining in said submergence-column and while in operation a super-head submergence-effect corresponding with the super-head pressure resulting from said energy-conversion.

11. In an airlift system comprising a primary airlift-member and also a second airlift-member having a submergence column supplied from the primary airlift-member, in combination, a primary airlift-member having an uptake column comprising an uptake-pipe which is provided in the lower part thereof with liquid-aeration means and is provided at the upper end thereof with a

three-channel junction in which the delivery-end of said uptake-pipe constitutes a supply-channel therefor, said junction also having an upwardly-extending channel for liquid-deaeration and energy-conversion, and arranged for deaerating the liquid of a spouting-column and returning such liquid in a counter-flow stream to said junction under a super-head pressure at the level of said delivery-end of said uptake-pipe; and, a junction-outlet channel in position and connected for transferring said deaerated liquid and the counter-flow stream thereof into the submergence-column of said second airlift-member by a stream maintained under said super-head pressure.

12. In a multilift apparatus for elevating liquid by the airlift method, in combination, a first airlift-member and a second airlift-member located in successive positions and also at successive elevations, respectively, and connected for conjoint operation, each said airlift-member comprising an uptake-tube having aeration means at the lower end thereof, and the uptake-tube of said first airlift-member having at the upper end thereof a super-head-forming means in position, connected and arranged for forming and maintaining a super-head column-increment for the submergence column of said second airlift-member, said successive airlift-members being each proportional and each positioned at such a height relative to the other that the air-supply pressure adequate to said first airlift-member and its super-head-forming means is also adequate to the submergence-effect required by said second airlift-member.

13. In a multilift apparatus for elevating liquid by the airlift method, in combination, a first airlift-member, a second airlift-member, and a third airlift-member located in successive positions and also at successive elevations, respectively, and connected for conjoint operation, each said airlift-member comprising an uptake-tube having aeration means at the lower end thereof, and the uptake-tubes of said first airlift-member and of said second airlift-member each having at the upper end thereof a super-head-forming means in position connected and arranged for forming and maintaining a super-head column-increment for the submergence column of a next following airlift-member, said three successive airlift-members being each proportional, and each positioned at a height relative to the other said members that the air-supply pressure adequate to said first airlift-member and its super-head-forming means is also adequate to the second airlift-member and its super-head-forming means, and also to the submergence-effect required by said third-airlift-member.

14. A multi-lift uniflow airlift system

comprising, in combination, a stream-conducting conduit continuous from the point of initial intake to the point of stream-discharge, and means appurtenant to said conduit and located at successive positions therein for first aerating and then deaerating a uniflow liquid stream and thereby subject the stream at each said position to a forwardly-impelling pressure by a resultant submergence-effect, one of said deaerating means comprising a kinetic-energy converter in position and connected for applying to the stream a super-head pressure and thereby augment said submergence-effect while maintaining on the stream a super-atmospheric pressure at all points in the length of said conduit, and said successive means for aeration and deaeration being placed and proportioned for applying said submergence-effects with an aggregate force corresponding to the height from said intake point up to said point of stream of discharge.

15. A multilift uniflow airlift system comprising, in combination, a stream-conducting conduit continuous from the point of initial intake to the point of stream-discharge, and means appurtenant to said conduit and located at successive positions therein, and including descending and ascending conduit formations, for first aerating and then deaerating a uniflow liquid stream and thereby subject the stream to an upflow at each said position and to a forwardly-impelling pressure by a resultant submergence-effect, a plurality of said deaerating means each comprising a kinetic-energy converter in position and connected for applying to the stream a super-head pressure and thereby augment said submergence-effects while maintaining on the stream a super-atmospheric pressure at all points in the length of said conduit, and said successive means for aeration and deaeration being placed and of proportions for applying said submergence-effects with an aggregate force corresponding to the height from said intake point up to said point of stream discharge.

16. A multilift uniflow airlift system comprising, in combination, a stream-conducting conduit continuous from the point of initial intake to the point of stream-discharge, and means located at successive positions in said conduit and including ascending and descending conduit formations for first aerating and then deaerating a uniflow liquid stream and thereby subject the stream first to a down-flow and then to an up-flow at each said position and to a forwardly-impelling pressure by a resultant submergence-effect, each one of said deaerating means being arranged and connected to also constitute a kinetic-energy converter for applying to the stream a

super-head pressure and thereby augment said submergence-effects while maintaining on the stream a super-atmospheric pressure at all points in the length of said conduit.

17. An airlift uptake column, comprising in combination, an uptake pipe provided in the lower part thereof with liquid-aerating means; and, a combined deaeration chamber and kinetic-energy converter of tubular form and constituting an upper extension for the uptake-pipe, and of a height to receive, and to retain during deaeration, the entire height of a spouting column of aerated liquid discharged upwardly thereinto from the uptake-pipe, said chamber being in position and proportioned for the formation therein of a down flowing counter-flow stream of the liquid deaerated from the spouting-column, and having a discharge port for said stream located below the zone of de-aeration.

18. An airlift uptake column comprising, in combination, an uptake pipe provided in the lower part thereof with liquid-aeration means; and, a combined deaeration chamber and kinetic-energy converter constituting an upper extension of the uptake-pipe, and having a combined counter-flow-receiving and streams-uniting chamber surrounding the discharge end of said pipe, said energy-converter being of a height to receive, and to retain during deaeration, the entire height of a spouting column of aerated liquid discharged upwardly thereinto from the uptake-pipe, and said chamber being in position and proportioned for receiving therein a counter-flow stream of the liquid deaerated from the spouting-column, and having a discharge port for said stream and located below the zone of deaeration.

19. In an airlift uptake column, in combination, an uptake-pipe provided in the lower part thereof with liquid-aeration means and provided at the upper end thereof with a three-channel junction which comprises the delivery-end of said uptake-pipe as a supply-channel therefor, said junction also having an upwardly-extending channel for liquid-deaeration and energy-conversion, and which extends beyond the height of a spouting head normal to a stream of aerated liquid discharged upwardly from said uptake-pipe, and is arranged for deaerating the liquid of said spouting head and returning such liquid in a counter-flow stream and thereby forming a super-head liquid column, and is coactive for maintaining this column under a plus-atmospheric super-head pressure at the level of said delivery-end of said uptake-pipe; and, a junction outlet channel in position and connected for conducting away from the junction the deaerated liquid and the counter-flow stream thereof while these are maintained under said super-head pressure.

20. In an airlift uptake column, in combination, an uptake-pipe provided in the lower part thereof with liquid-aeration means and provided at the upper end thereof with a
5 three-channel junction which comprises a flowage chamber and three channels appurtenant thereto, first, the delivery-end of said uptake-pipe which extends into the interior of said chamber and is a supply-channel
10 therefor; second, an upwardly-extending channel for liquid-deaeration and energy-conversion, and which extends beyond the height of a spouting-column normal to a stream of aerated liquid discharged upwardly
15 ly from said uptake-pipe, and is proportioned and arranged for deaerating the liquid of said spouting-column and returning such liquid in a counter-flow stream and under a super-head pressure into said flowage chamber;
20 and, third, a junction outlet channel in position and connected for conducting away from said flowage-chamber the deaerated liquid and the counter-flow stream thereof while these are under said super-head pressure.
25

21. In an airlift pair comprising a primary airlift-member and a secondary airlift-member, in combination, an uptake pipe for the primary airlift-member and having
30 an upper terminal member consisting of a combined deaeration chamber and kinetic-energy converter arranged and operable for delivering de-aerated liquid from a spouting column to an outlet passageway comprised in said primary airlift-member;
35 and, a submergence column for the secondary airlift-member and extending to a level higher than said pipe by a distance greater than a head of liquid representing the pressure of said spouting-column, said passageway being arranged for and forming a conduit in position for delivering liquid from said deaeration chamber to said submergence column
40 at a position therein below a normal range of variation in the top surface of the submergence therein.
45

22. In an airlift pair comprising a primary airlift-member and a secondary airlift-member, in combination, an uptake pipe for the primary airlift-member and having
50 an upper terminal member consisting of a tubular combined deaeration chamber and kinetic-energy converter arranged and connected for delivering deaerated liquid from a spouting column to an outlet passageway comprised in said primary airlift-member
55 and located at a level lower than the discharge end of said pipe; and a submergence column for the secondary airlift-member and extending to a level higher than said pipe by a distance greater than a head of liquid representing the pressure of said spouting-column, said passageway being in
60 position and connected for forming a con-

duit for delivering liquid from said deaeration chamber to said submergence column at a subsurface position therein.

23. In an airlift pair comprising a first airlift-member and a second airlift-member, in combination, an uptake pipe for the first airlift-member and having an upper terminal member consisting of a columnar combined liquid deaerator and kinetic-energy converter arranged and operable for
70 deaerating therein the liquid of a spouting column projected thereinto from said uptake pipe; a submergence column for the second airlift-member and extending to a level higher than said pipe by a distance greater than a head of liquid representing the pressure of said spouting-column; and,
75 means for delivering deaerated liquid from said deaerator to said submergence column at a position therein below the top surface of the submergence therein.

24. In an airlift system comprising an airlift pair having a first airlift-member and a second airlift-member, in combination, an uptake pipe for the first airlift-member; a combined liquid deaerator and kinetic-energy converter in position and arranged for receiving a spouting column of aerated liquid discharged upwardly from
said pipe; a submergence-column for the second airlift-member and extending to a level higher than said pipe by a distance greater than a head of liquid representing the pressure of said spouting-column; and
a passageway chamber surrounding the discharge end of said pipe and connecting with said deaerator and said submergence column through separate channels, respectively, and arranged for delivering deaerated liquid into said submergence-column below the top surface of the submergence therein.

25. In an interconnected airlift pair comprising a first airlift-member and a second airlift-member arranged in series, in combination, an uptake column for the first airlift-member and having an uptake tube; a submergence column for the second airlift-member and extending above the level of said uptake tube by the height of a spouting-head line in said uptake column; and,
an economizer-regulator appurtenant to and connecting said uptake and submergence columns and comprising a channel positioned for receiving a spouting-column projected upwardly thereto from the uptake tube, and for retaining during deaeration, the liquid of, and the full height of the spouting column, and then delivering this liquid deaerated and by a counter-flow stream into the submergence column in a position for applying thereto a super-head pressure corresponding to the pressure-head of the spouting column.

26. In a uniflow airlift system, in com-

5 bination a column-pair comprising the up-
 take-column of one airlift-member and the
 submergence-column of a second and next
 succeeding airlift-member, and provided at
 10 the upper part thereof with a four-chan-
 nel economizer-regulator apparatus having
 therein, first a supply-channel consisting of
 the discharge-end of the uptake-pipe of said
 uptake-column; second, an energy-converter
 15 channel above said pipe-end and of a height
 for retaining during deaeration a spouting
 column discharging upwardly from said
 pipe-end; third, a column-connecting chan-
 nel connecting the lower end of said energy-
 converter channel with said submergence-
 column; and, fourth, an upper end extension
 20 of the submergence-column which extends
 above a level corresponding to the height of
 a pressure head-normally formed in said
 converter, and which is thereby positioned
 to receive and contain a super-head column-
 increment for adding to the otherwise nor-
 mal submergence-effect of the liquid sub-
 25 mergence column in said second airlift-
 member.

27. In a multilift system for elevating
 liquids by the airlift method, in combina-
 tion, a plurality of successive and coacting
 column-pairs each comprising an uptake
 30 column for aerated liquid and a down-flow
 column for a deaerated liquid, and each
 down-flow column being an intermediate for
 connecting two of said uptake columns; and,
 two economizer-regulators at successive posi-
 35 tions in the system and each comprising an
 upper-end portion of one uptake column and
 of one down-flow column, and provided with
 channel and chamber spaces connecting and
 arranged for deaerating and economizing
 40 the residual energy of an upflowing aerated
 liquid stream and thereby produce a plus-
 atmospheric pressure and a super-head col-
 umn-increment in said down-flow column,
 and for transmitting the stream after
 45 deaeration into the down-flow column while
 supplying thereto said super-atmospheric
 pressure, said economizer-regulators being
 proportioned and positioned for each to ap-
 ply to said stream during variations in the
 50 operation thereof a pressure and a liquid-
 supply counteractive of said stream varia-
 tions.

28. In an airlift pair comprising a first
 55 airlift-member and a second airlift-member
 each provided with an uptake pipe and with
 super-head-forming means, and connected in
 series and for interactive operation, in com-
 bination, a first airlift-member in position
 and connected for operation under a sub-
 60 mergence normal thereto and by an air-sup-
 ply pressure normal to said submergence,
 and connected to supply liquid to the sub-
 mergence column of the second airlift-mem-
 ber by a subsurface stream under pressure;
 a second airlift having the submergence col-

umn thereof in position and connected for
 receiving said stream at a subsurface height
 therein; and air-supply means connected for
 delivering air under pressure and for liquid-
 aeration to the uptake pipe of each said air-
 lift, said second airlift being positioned at a
 70 height relative to said first airlift for the
 flow of air thereinto from the air supply
 pressure at which the air flows into said first
 airlift, and thereby interactively so regulate
 75 the operation of the two airlift-members
 that an excess in ratio of action in either
 said airlift immediately restricts the rate of
 up-flow in the airlift having such excess of
 action and accelerates the rate of upflow in
 80 the other said airlift, for thereby restoring
 from an unbalanced to a balanced ratio the
 rates of action in the two said airlift-
 members.

29. In an airlift pair comprising a pri- 85
 mary airlift-member and a secondary airlift-
 member each provided with an uptake pipe
 and with super-head forming means, and
 connected in series for interactive operation,
 in combination, a primary airlift-member in 90
 position and connected for operation under
 a submergence normal thereto and by an air-
 supply pressure normal to said submergence,
 and also connected to supply liquid to the
 submergence column of the secondary by a 95
 submergence stream under pressure; a sec-
 ondary airlift-member having the sub-
 mergence column thereof in position and
 connected for receiving said stream at a sub-
 surface height therein; and air-supply 100
 means connected for delivering air under
 pressure and for liquid-aeration to the up-
 take pipe of each said airlift, said secondary
 airlift-member being positioned at a height 105
 relative to said primary airlift-member for
 the flow of air thereinto from the air-supply
 pressure at which the air flows into said
 primary airlift-member, and thereby with-
 out a change of air-supply pressure so reg-
 110 ulates the operation of the two airlifts that
 an excess in ratio of action in either said
 airlift reduces the rate of upflow in the air-
 lift-member having such excess of action and
 accelerates the rate of upflow in the other
 said airlift-member, for thereby restoring 115
 from an unbalanced to a balanced ratio the
 rates of action in the two said airlift-
 members.

30. In apparatus for elevating liquid by
 the airlift method, in combination, a first 120
 uptake-column comprising at the upper end
 thereof a three-channel-junction member
 provided with a super-head-forming kinetic-
 energy converter and with an outlet chan-
 125 nel; a second uptake-column positioned for
 delivering a liquid stream to a position
 higher than the junction member of said
 first column; liquid-aerating means apurte-
 nant to the lower part of each said uptake
 column; a down-flow column connecting 130

with, and supplying liquid to, the lower part of said second uptake-column at a position therein below said aerating means thereof, said down-flow column being of a length operable for providing the submergence-effect for said second uptake-column, and having its upper end extending above the level of the super-head formed in said converter, and said outlet channel of said junction member being in position and connected for transmitting a stream of deaerated liquid from said junction member and into said down-flow column and thereby supply liquid to said second up-take column, and also thereby form and supply by an under-feed thereto a super-head of liquid contained in the down-flow column and located therein above the path of flowage of said stream and also located intermediate to the two said uptake columns and positioned for serving as a reserve supply in and the interactive regulation of the co-active operation of these uptake columns.

31. In multilift apparatus for elevating liquids by the uniflow airlift method, in combination, an initial uptake receiving-column having at its upper end a deaerating and super-head-forming means; a terminal uptake discharging-column positioned at an elevation higher than the receiving column; liquid-aeration means in the lower part of each said uptake column; and, a three-conduit system intermediate to and connecting said receiving-column and said discharge-column, and connected for being supplied from said super-head-forming means of said receiving-column, and connected for supplying liquid to said discharging-column at a position below the aeration means of this column, said three-conduit system comprising two down-flow columns connecting one of them at the top part thereof with said super-head-forming means of the receiving column, and the other of them connecting at the lower end thereof with the lower end of said discharging column, and said two down-flow columns being connected into one stream-conducting path by an intermediate uptake column having aeration means in the lower part thereof and having a deaeration and super-head-forming means at the upper part thereof, each of said super-head-forming means being thereby in position and connected for each applying a plus-atmospheric pressure to a downturn portion of the uniflow stream, and also connected through said columns intermediate thereto, for a reciprocal regulative action thus transmittable through the liquid stream and from each said means to the other.

32. In a series airlift system, in combination, an up-take pipe and a connected submergence column therefor; air-supply means comprising liquid-aeration means for

the up-take pipe; means for supplying liquid to said submergence column at a sub-surface position therein and under a super-head pressure; a kinetic energy converter constituting an upper end extension of said uptake-pipe and operative for forming a super-head pressure of the liquid at the discharge end of said pipe; and means for conducting the liquid out from said energy converter for discharge in a stream at a sub-surface position therein and under said super-head pressure, said aeration means being thus operable upon a liquid column which is received into said submergence column in a stream flowing against a super-head pressure, and is discharged from the uptake column in a stream flowing against a super-head pressure obtained by a conversion of kinetic energy within said uptake-pipe extension, and said liquid column extending between and coacting with, said supply stream and its super-head pressure and said discharge stream and the super-head pressure thereof, for thereby transmitting a regulative action from each said stream to the other on the occurrence of a variation in the relative rates of flowage of said supply and discharge streams.

33. In an airlift system comprising a series of airlift-members each provided with an uptake pipe and organized to constitute two airlift pairs,—namely, a primary pair and a secondary pair,—and having each of these pairs comprising a first airlift-member and a second airlift-member connected in series and for interactive operation, and having the second airlift-member of the primary-pair also constituting the first airlift-member of the secondary pair, in combination, a primary airlift-pair comprising a first airlift-member in position and connected for operation under a submergence normal thereto and by an air-supply pressure normal to said submergence, and also connected to supply liquid to the submergence column of the second airlift-member of this primary pair by a subsurface stream and under a super-head pressure, said primary pair also comprising a second airlift-member having the submergence column thereof in position and connected for receiving said liquid stream at a subsurface position therein; a secondary airlift-pair comprising as the first airlift-member thereof the said second airlift-member of the primary pair, and also comprising a second airlift-member having the submergence column thereof in position and connected for receiving in a subsurface position therein a stream of liquid discharged from said first airlift-member of this secondary pair, this airlift-member being also the second airlift-member of the primary pair; and, air-supply means connected for supplying to each said airlift-member, air at a pressure normally required

by the total submergence of each said airlift-member, respectively, and thereby coact in so regulating the inter-active operation of the combined airlift-pairs that the restoring
 5 from an unbalanced to a balanced ratio of the rates of action in the airlift-members of either said pair shall thereby interact for the restoring to a balanced ratio the rates of action in and as between the said airlift-
 10 members of the other said pair, and thereby overcome an unbalanced ratio of action and restore a balanced ratio of action as between all the airlift-members of the series.

34. The hereindescribed method of utilizing, in an airlift pair which comprises a primary airlift-member and a secondary airlift-member, the energy of the spouting column of aerated liquid discharged upwardly from the uptake pipe of an airlift,
 20 which consists in laterally confining the spouting column during deaeration and for the entire height thereof, within a columnar extension of the said uptake pipe, and thereby produce a downflow stream having a super-head pressure, and then transferring this pressure and stream for use in a coacting apparatus and through a passageway below the level of said upward discharge of the spouting column.

35. The hereindescribed method of utilizing, in an airlift pair which comprises a primary airlift-member and a secondary airlift-member, the energy of the spouting column of aerated liquid discharge upwardly from the uptake pipe of an airlift-member, which consists in laterally confining the spouting column during deaeration and for the entire height thereof, within a columnar extension of the said uptake pipe, and thereby
 40 produce a down-flow stream having a super-head pressure, and then transferring this pressure and stream for use in a coacting apparatus and through a passageway below the level of the pipe-end from which the spouting column is upwardly discharged.

36. The hereindescribed method for air-lifting liquids, it consisting in flowing the liquid in a continuous unifold stream from the initial intake point of a primary uptake column to the point of discharge in a final uptake column, and while confined in a continuous conduit extending from said intake point to said discharge point subjecting said flowing stream to a plurality of successive down-turn and up-turn flowages in alternation, and subjecting the stream at each said up-turn to aeration, and at each said down-turn to deaeration and conversion of spouting-column-energy into a super-head pressure, and thereby form and maintain on the down-turn portions of the stream the pressure of a super-head of liquid intermediate to the path of the stream and the atmosphere.

37. The hereindescribed method of air-

lifting liquids in a unifold stream, it consisting first, in subjecting an intake stream in the uptake pipe of a primary uptake column to submergence-effect and to aeration proportioned for delivering this stream out
 70 of said pipe with a spouting-head pressure; second, transferring the stream out from said primary column at a level at which the stream is subject to said spouting-head pressure, and thence through an intervening conduit comprising stream-impelling means to the lower end of a liquid-discharging uptake column; third, subjecting the stream in said discharge uptake column to an aeration and to the force of a stream-impelling means
 80 proportioned for elevating said stream to a discharge outlet, said discharge uptake column being located with the aeration level thereof above the normal submergence level of said primary uptake column, and said
 85 intermediate stream-impeller having a force for lifting the liquid from the level of said discharge level of the primary column, up to the normal submergence level of said discharging uptake column, and, maintaining the liquid from its entrance to said primary column and throughout its flowage to the outlet of said discharging column, continuously under a pressure greater than atmospheric pressure and not less at any point
 95 than the amount of the pressure produced by the spouting-head, whereby the described unifold stream is protected from atmospheric interference and is maintained throughout the entire course thereof under
 100 a pressure in excess of atmospheric pressure.

38. A method for interactively regulating in a multilift unifold airlift system the operation of two successive airlift-members each of which comprises an uptake-column
 105 provided with a coacting submergence-column, said method consisting in discharging the stream of liquid from each uptake column into the submergence-column of a next following airlift-member and by a stream
 110 under the pressure of a super-head reserve-supply of the liquid column therein, and upon a change of pressure arising in the stream discharging from one uptake-column, transmitting the force of such change
 115 of pressure to the submergence column of the other airlift-member and thereby proportionately vary the resistance to flowage of the stream into the said submergence column of the other airlift-member, and thereby
 120 concurrently with an increase of the head of one said reserve-supply and a consequent reduction in the rate of action of one said airlift-member, drawing upon and correspondingly decreasing the head of the other
 125 said reserve-supply to thereby produce a counter-balancing increase in the rate of action of the other said airlift-member of the system.

39. A method for interactively regulating 130

in a multilift uniflow airlift system the operation of three or more successive airlift-members each of which comprises an uptake-column provided with a coacting submergence-column, said method consisting in discharging the stream of liquid from each uptake column into the submergence-column of a next following airlift-member and by a stream under the pressure of a super-head reserve supply of the liquid column therein, and upon a change of pressure arising in the stream discharging from the uptake-column of an intermediate airlift-member, transmitting the force of such change of pressure to the submergence column of two next adjacent airlift-members, one of these being located forwardly and the other rearwardly in the system, from the said intermediate airlift-member in which said change of pressure first arises, and thereby proportionately vary the resistance to flowage of the stream into the said submergence columns of such next adjacent airlift-members, and thereby concurrently with an increase of the head of one said reserve-supply and a consequent reduction in the rate of action of one said airlift-member, thereby producing a counter-balancing change in the rate of action of two other said airlift-members of the system.

40. The herein described improvement in the art of air-lifting liquids in a multi-stage airlift-system by successive stages and in a uniflow stream, which consists, first, in aerating a liquid main-stream in the lower part of a first uptake pipe of the system and thereby and under submergence-effect, elevating this main-stream while aerated to the upper discharge end of said first uptake pipe; second, deaerating and segregating a peripheral portion of the main-stream at said discharge pipe-end and passing this segregated portion as a peripheral deaerated stream directly into a stream-enclosing conduit located in a subsurface position and under a super-atmospheric pressure; third, passing upward and deaerating while under lateral columnar enclosure, the central spouting-column portion of said main-stream and converting the kinetic energy thereof into spouting-column-head pressure while forming the liquid thereof into a down-flow liquid stream; fourth, reuniting this down-flow stream with, and applying the spouting-column-head pressure thereof to said peripheral stream and thereby forming a restored unaerated main-stream under a super-atmospheric pressure, all of the said operations being concurrent each with the other.

41. The hereindescribed improvement in the art of air-lifting liquids in a multi-stage airlift-system by successive stages and in a uniflow stream, which consists, first, in aerating a liquid main-stream in the lower part

of a first uptake pipe of the system and thereby and under submergence-effect, elevating this main-stream while aerated to the upper discharge end of said first uptake pipe; second, deaerating and segregating a peripheral portion of the main-stream at said discharge pipe-end and passing this segregated portion as a peripheral deaerated stream directly into a stream-enclosing transfer conduit; third, passing upward and deaerating while under lateral columnar enclosure, the central spouting-column portion of said main-stream and converting the kinetic energy thereof into spouting-column-head pressure while forming the liquid thereof into a down-flow liquid stream; fourth, reuniting this down-flow stream with, and applying the spouting-column-head pressure thereof to said peripheral stream before entrance thereof into said transfer conduit; fifth, transferring the said reunited peripheral and down-flow streams these now forming a restored unaerated main-stream into a submergence column connecting with a second and more elevated uptake-pipe of the airlift system, this stream-transference being made into said submergence column through a stream-enclosing conduit at a subsurface position and under a super-atmospheric pressure, and all of the said operations being concurrent each with the others, and continuous during an operating period of the multi-stage system.

42. The herein described improvement in the art of air-lifting liquids in a multi-stage airlift-system by successive stages and in a uniflow stream, which consists, first, in aerating a liquid main-stream in the lower part of a first uptake pipe of the system and thereby and under submergence effect, elevating this main-stream while aerated to the upper discharge end of said first uptake pipe; second, deaerating and segregating a peripheral portion of the main-stream at said discharge pipe-end and passing this segregated portion as a peripheral deaerated stream directly into a stream-enclosing transfer conduit; third, passing upward and deaerating while under lateral columnar enclosure, the central spouting-column portion of said main-stream and converting the kinetic energy thereof into spouting-column-head pressure while forming the liquid thereof into a down-flow liquid stream; fourth, reuniting this down-flow stream with, and applying the spouting-column-head pressure thereof to said peripheral stream before entrance thereof into said transfer conduit; fifth, transferring the said reunited peripheral and down-flow streams these now forming a restored unaerated main-stream into a submergence column connecting with a second and more elevated uptake-pipe of the airlift system, this stream-transference being made into said

submergence column through a stream-enclosing conduit at a subsurface position and under a super-atmospheric pressure; sixth, repeating in and in connection with said second uptake-pipe the several described operations as conducted in connection with said first uptake-pipe, and thereby bring two successive aerated main-stream portions one in each of said uptake-pipes, respectively into a coactive and inter-regulative relation through one intervening and deaerated submergence column, and all of the said operations being concurrent each with each of the others.

43. In an airlift system organized for air-lifting a liquid main-stream by a series of successive stages and in a uniflow stream, in combination, a first uptake pipe in position, air-supplied and connected for receiving and aerating at the lower end thereof the said main-stream, and under submergence-effect to upflow this main-stream to and out of the upper discharge-end of this first uptake pipe, and thus to deliver said main-stream in the form of a peripheral deaerating stream which surrounds a central stream in which the aeration is there concentrating with an accelerating coalescence and a streams-segregating action; a second and more elevated uptake pipe air-supplied and connected for receiving and reaerating at the lower end thereof the said main-stream; a submergence-column having an unclosed upper end extending higher than the discharge-end of said first uptake pipe, and connecting at the lower end thereof with and thereby closing the lower end of said second uptake pipe; a stream-enclosing transfer conduit in position and connected for receiving the main-stream subsequent to a deaeration thereof, and connecting with said submergence-column at a subsurface position thereof, thereby to deliver the main-stream into the submergence column under a super-atmospheric pressure; and, a laterally-enclosed stream-deaerating top-vented column which extends upward from, and receives said central stream as a spouting column from said first uptake-pipe, and also connects for delivering into said transfer-conduit, the said combination elements being proportioned and organized as herein described for subjecting said peripheral and central streams to a segregative action on these streams nearing the discharge end of said first uptake-pipe and passing said peripheral stream directly to the transfer-conduit, and for passing upward and deaerating in said top-vented column said central stream and forming the liquid thereof into a down-flow stream which at said transfer conduit reunites with said peripheral stream thereby forming and thereby adding spouting-head

pressure to a restored and deaerated main-stream that flows through said submergence column for supplying said second uptake-pipe and for being therein reaerated for the airlifting thereof through a second stage of the series of stages.

44. In a multi-stage airlift system comprising a series of airlifts connected and equipped for elevating a uniflow stream by successive aerations and deaerations while continuously under a super-atmospheric pressure, in combination, two economizer-governors located, respectively, at successive positions and elevations in and coactively connected with each other by subsurface streams and through a pair of columns which comprises one down-flow liquid-submergence-column non-aerated and under super-head pressure, and comprises one uptake column bottom-connected with and supplied with liquid from said submergence-column, and when the system is in operation having therein a longitudinally-elastic aerated fluid column through which liquid is supplied from the first and lower said economizer-governor and delivered into the said second and more elevated one of them, said second and more elevated economizer-governor being in position and connected for operation in a resistant manner against said first and lower economizer-governor, by a force transmitted, first, through an intervening elastic column tending to yield under such resistant action, and, second, through a non-elastic liquid column in said submergence column having a resistant inertia, these two factors, of elasticity and inertia, operating coactively sometimes forwardly and at other times backwardly to create a time-interval as between a transmitted impulse arising or developed in one said economizer-governor, and the time such impulse becomes effective on the other said economizer-governor, substantially as specified.

45. A multilift uniflow airlift system comprising a first uptake column and a second uptake column arranged in successive positions and at successive elevations respectively; a submergence column intermediate to said uptake columns and open at its upper end to atmosphere and connected at its lower end in continuity to said second uptake column for supplying liquid thereto, the open upper end of said submergence column extending above the height of a liquid-head and submergence effect normal to said second uptake column; and means cooperating between said submergence column and first uptake column for deaerating an aerated upflowing stream of liquid and transmitting this deaerated liquid into said submergence column at a point below said open upper end for forming thereby in said sub-

mergence column a super-head column-increment located above the flowage path of the uniform flow stream.

46. A multilift uniflow airlift system comprising a first uptake column and a second uptake column arranged in successive positions and at successive elevations respectively; a submergence column intermediate to said uptake column and open at its upper end to atmosphere and connected at its lower end in continuity to said second uptake column for supplying liquid thereto, the open upper end of said submergence column extending above the height of a liquid-head and submergence effect normal to said second uptake column; and means cooperating between said submergence column and first uptake column and connected to the first uptake column near the upper end of said uptake column and comprising channel means communicating between the first means and the upper end of the submergence column for deaerating an aerated upflowing stream of liquid and transmitting this deaerated liquid into said submergence column at a point below said open upper end for forming thereby in said submergence column by an under-flow feed a super-head column-increment located above the flowage path of the uniflow stream.

47. A multilift uniflow airlift system comprising a first uptake column provided with an energy-converter located above the discharge end of said uptake column and cooperating with the uptake column; a second uptake column, the uptake columns being arranged in the system at successive elevations respectively and each being provided with aeration means; a submergence column intermediate to said uptake columns open at its upper end to atmosphere and connected at its lower end for continuous flow of liquid to the second uptake column, the open upper end of the submergence column forming a reserve-supply chamber; and means for transmitting from a position below said energy-converter into said submergence column at a point thereof below the line of the discharge end of the first uptake column a stream of unaerated liquid forming part of the uniform stream for thereby supplying said chamber with reserve liquid having a plus-atmospheric pressure derived from said energy-converter.

48. A multilift uniflow airlift system comprising a first uptake column provided with an energy-converter located above the discharge end of said uptake column and cooperating with said uptake column; a second uptake column, the uptake columns being arranged in the system at successive elevations respectively and each being provided with aeration means; a submergence column intermediate to said uptake columns open at its upper end to atmosphere and

connected at its lower end for continuous flow of liquid to the second uptake column, the open upper end of the submergence column forming a reserve-supply chamber; and a channel member cooperating between said energy-converter and the submergence column for transmitting an unaerated liquid stream from a position below said energy-converter into said submergence column at a point thereof below said reserve-supply chamber for thereby supplying said chamber by an underfeed thereto with a reserve supply of liquid located in the submergence column between the flowage path of the uniflow stream and the outlet to the atmosphere of said column.

49. In a multilift uniflow airlift system, in combination, a first uptake pipe; a second uptake pipe; means for supplying air under greater than atmospheric pressure to each of said pipes; a submergence pipe arranged intermediately to the uptake pipes and open at its upper end to atmosphere and connected at its lower end for continuity of flow to the second uptake pipe for supplying liquid thereto, the upper end of the submergence pipe extending above the height of a liquid head and submergence effect normal to the second uptake pipe; and an energy-converter comprising a lower chamber arranged around the discharge end of the first uptake pipe, an intermediate chamber communicating with said lower chamber, a neck portion open at its upper end and communicating at its lower end with the intermediate chamber, and a member providing a channel communicating between said lower chamber and the submergence pipe at a point thereof below the level of the upper line of the discharge end of the first uptake pipe.

50. In a multi-lift uniflow airlift system, in combination, a first uptake pipe; a second uptake pipe; means for supplying air under greater than atmospheric pressure to each of said pipes; a submergence pipe arranged intermediately to the uptake pipes and open at its upper end to atmosphere and connected at its lower end to the second uptake pipe for supplying liquid thereto at a point adjacent to and below the means for supplying air to said pipe, the upper end of the submergence pipe extending above the height of a liquid head and submergence effect normal to the second uptake pipe; and an energy-converter comprising a lower chamber arranged around the discharge end of the first uptake pipe, an intermediate chamber communicating with said lower chamber and disposed over the discharge end of the first uptake pipe, a neck portion open at its upper end and communicating at its lower end with the intermediate chamber, and a member providing a channel communicating between

said lower chamber and the submergence pipe at a point thereof below the level of the discharge end of the first uptake pipe.

51. In a multilift uniflow airlift system, in combination, an uptake pipe; means for supplying air under greater than atmospheric pressure to the lower end of said pipe; and an energy converter having a flaring portion open at its lower end and having a neck portion open at its upper end and communicating at its lower end with the upper interior of said flaring portion; the energy converter being disposed over the discharge end of the uptake pipe, the axis of the uptake pipe and the axis of said energy converter being in alignment and the discharge end of the uptake pipe lying substantially in the plane of the lower end of said flaring portion.

52. In a multilift uniflow airlift system, in combination, an uptake pipe; means for supplying air under greater than atmospheric pressure to the lower end of said pipe; and an energy converter having a substantially straight sided lower chamber, a flaring portion constituting an intermediate chamber, a neck portion open at its upper end and communicating at its lower end with the upper end of the intermediate chamber, and a laterally extending member providing a channel communicating with

said lower chamber; the energy converted being arranged relative to the uptake pipe so that said lower chamber surrounds the discharge end of the uptake pipe and said flaring portion is disposed over the discharge end of the uptake pipe, the axis of the uptake pipe and the axis of the energy converter being in alignment, the discharge end of the uptake pipe lying substantially in the plane of the lower end of said flaring portion, and the upper line of said channel being below the level of the discharge end of the uptake pipe.

53. In a multi-lift uniflow airlift system substantially as described, an energy converter comprising a flaring portion open at its lower end, and a neck portion open at its upper end and communicating at its lower end with the upper interior of said flaring portion.

54. In a multilift uniflow airlift system substantially as described, an energy converter comprising a lower chamber open at its lower end, a flaring portion constituting an intermediate chamber, a neck portion open at its upper end and communicating at its lower end with said intermediate chamber, and a laterally extending member providing a channel communicating with said lower chamber.

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