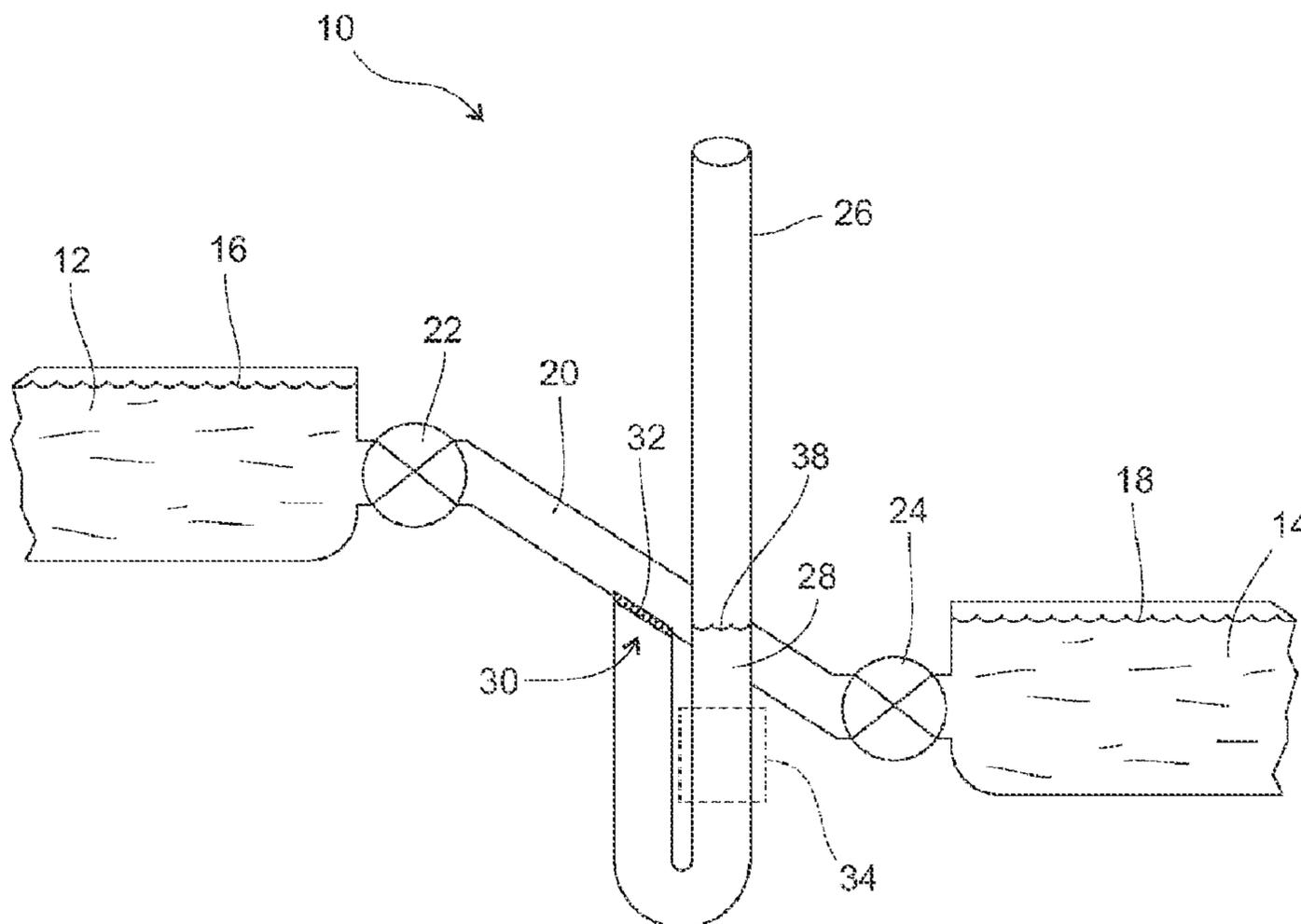




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 (54) Title: FISH PASSAGE APPARATUS WITH HYDROELECTRIC POWER GENERATOR



(57) **Abrégé/Abstract:**

An improved fish passage apparatus is combined with hydroelectric power generation to facilitate migration of fish between water bodies of different heights with minimal injury or trauma to fish. It may also be optimized for power generation when fish are not moving through it. The fish passage apparatus comprises a connecting tube providing fluid communication between upper and lower water bodies, an upper valve in the connecting tube adapted to control flow of water to or from an upper water body, a lower valve in the connecting tube adapted to control flow of water to or from a lower water body, and a working tube opening into the connecting tube between the upper and lower valves a working portion of which extends functionally vertical to above a water level of the upper body of water and to below a water level of the lower body and is vented at its top such that water can flow freely in and out of the working portion.

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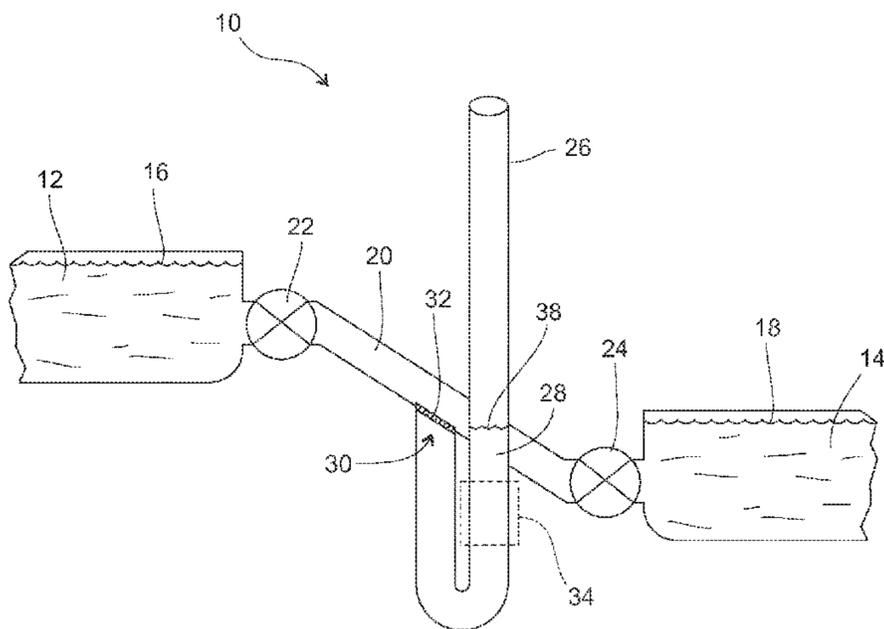


Fig. 1

(57) Abstract: An improved fish passage apparatus is combined with hydroelectric power generation to facilitate migration of fish between water bodies of different heights with minimal injury or trauma to fish. It may also be optimized for power generation when fish are not moving through it. The fish passage apparatus comprises a connecting tube providing fluid communication between upper and lower water bodies, an upper valve in the connecting tube adapted to control flow of water to or from an upper water body, a lower valve in the connecting tube adapted to control flow of water to or from a lower water body, and a working tube opening into the connecting tube between the upper and lower valves a working portion of which extends functionally vertical to above a water level of the upper body of water and to below a water level of the lower body and is vented at its top such that water can flow freely in and out of the working portion.

## 2 FISH PASSAGE APPARATUS WITH HYDROELECTRIC POWER GENERATOR

## 4 BACKGROUND

Field of the Invention

6 This invention relates to tubes connected between two bodies of water of  
different elevations optimized for power generation, and more specifically to such a  
8 configuration adapted for fish migration between the bodies of water.

Prior Art

10 It is well known that power generators between bodies of water of different  
heights extract potential energy from the flow of water. Hydropower generation  
12 systems typically rely on water flow from dams through turbines that run generators.  
However, turbine based systems do not allow for fish migration beyond the dams or  
14 often injure fish passing through them. To avoid injury and death to fish passing  
dams, high cost systems are employed. Currently, the primary bypass methods are a  
16 series of pools as fish ladder apparatus for upstream migration and spillways for  
downstream migration. Unfortunately, these methods are also problematic due to  
18 passage delays, increases in dissolved gasses, fish de-scaling, fish disorientation,  
increased predation, injury and so forth. Further, they are only effective with head  
20 heights less than about 90 feet. For dams with a head of more than 90 feet, fish must  
be trapped and transported around or lifted over the dam due to excessive mortality  
22 rates and the inability of fish to completely climb the ladders.

It is an object of the present invention to provide a combination fish passage  
24 apparatus and hydropower generator that is conducive to fish migration with the least

2 possible injury or trauma to the fish. It is another object that the combination be  
economically effective for head heights ranging from very small to very large. It is  
4 still another object that extraction of potential energy of the water between two bodies  
of water of different heights be optimized.

## 6 SUMMARY

8 These objects are achieved in the combination fish passage apparatus and  
power generator through an oscillating column of water as described herein which  
provides a connecting tube between two bodies of water with a pair of valves  
10 controlling water flow at the upper and lower bodies of water. When the upper valve  
is opened water surges from the upper body of water having significant potential  
12 energy in its momentum. To capture that energy a working tube, functionally  
vertical, is connected to the connecting tube between the valves. Flow of water to the  
14 lower body of water is interrupted with the lower valve closed thereby directing flow  
into the working tube. The momentum of the flow causes an overshoot of the water  
16 level in the working tube past the water level of the upper body of water by 50  
percent or more before it falls back and then rises again in a wave-like decaying  
18 motion until eventually it equalizes at the water level of the upper body of water.  
That higher water level in the working tube may be captured by quickly closing the  
20 upper valve, thereby creating a head relative to the water level of the lower water  
body greater than that between the two bodies of water. The lower valve is then  
22 opened and the sudden release of water from the working tube causes the water level  
in the working tube to drop below the water level of the lower body of water in a  
24 similar wave-like decaying motion until the working tube water level equalizes with

2 that of the lower body of water. Once the proper water level in the working tube is  
achieved, then the lower valve is closed and the upper valve can be opened again to  
4 start another cycle.

6 One or more power generation systems (hereinafter “generator” including all  
supporting structures and apparatus’) are installed to operate in cooperation with the  
movement of the water in the working tube such that the generator may operate in the  
8 normal manner of an electricity generator as that water moves through a traditional  
generator. For these purposes, use of the term ‘generator’ is deemed to include any  
10 and all power takeoff mechanisms to convert water flow to rotation of a traditional  
generator, movement of a linear generator, movement of a point absorber, movement  
12 of air above the water as in a water piston, or other means for extracting energy such  
as piezoelectric devices, hydraulic and /or other weight induced generators, and  
14 turbines in combination with traditional electric generators, etc.

For a traditional generator, when the lower valve is opened quickly, water  
16 from the working tube surges out. It is that flow that operates the generator. All or  
virtually all of the potential energy captured in the working tube is extracted ideally  
18 when there is no or minimal flow to the lower water body, that is, all momentum from  
the initial surge from the working tube is extracted by the generator when the water  
20 level in the working tube reaches the water level of the lower body of water.

Necessarily, for a traditional generator, the generator should be below the level of the  
22 lower water body and the working tube extends below the water level of the lower  
body of water. For a traditional generator it may also be important to rectify the  
24 water flow so that the back-flowing water does not flow against the turbine and

2 potentially cause damage. By rectifying the bidirectional flow into a unidirectional  
flow, the rising surge in addition to the falling surge in the working tube will spin the  
4 generator. Although, by extracting energy from the surge as it rises or falls will  
ensure that the overshoot, if any, is minimal.

6 For other technologies that may be employed, the generator may be located as  
appropriate relative to the water flow and surge, which are deemed included in this  
8 representative description. That is, it is recognized that although this description is  
given in terms of water moving to the lower body of water, however, it should be  
10 understood that energy can also be extracted from water surging upwards into the  
working tube from the upper water body by suitably operating the upper and lower  
12 valves. These and all other manner of extracting potential energy from the upper  
body of water being at an elevation above the lower body of water are deemed  
14 included in the present description, which is deemed representative of all other such  
manner.

16 Valves of any appropriate design are suitable. Such valves may be based on  
butterfly, knife, slide, gate and diaphragm mechanisms for example, or any other and  
18 may be operated pneumatically, electrically, etc. or even manually. All are deemed  
included herein as possible mechanisms.

20 It is understood that when a traditional generator is not operating to extract  
energy from the working tube water flow, the surge of water out of the working tube  
22 when the lower valve is opened while the upper valve is closed will cause an  
overshoot downward past the water level of the lower body of water similar to the  
24 overshoot upward in the working tube above the upper body of water as described

2 previously. That lower level can be captured by quickly closing the lower valve. This  
lower level will then be the effective lower level when the upper valve is opened  
4 which will cause an even greater overshoot in the working tube upward past the upper  
water body level. This cycle can be repeated until there is a maximum head in the  
6 working tube.

It is understood that this invention may be well implemented as providing an  
8 improved method of fish migration between two bodies of water, upstream and or  
downstream. In this implementation, it is important that the valves be opened and  
10 closed in such a manner as to not injure the fish. Experimentation has shown that this  
will likely require the valves to open and close less quickly, which will compromise  
12 to some extent the advantage described above in power generation. As illustrated in  
the figures, the fish will pass through the connecting tube between the valves without  
14 passing into the working tube. In fact, a screen or other device will be installed to  
prevent fish from entering the working tube thereby ensuring that fish are never in  
16 danger from a power takeoff system. In addition, portions of the connecting tube may  
also serve as resting places during fish passage.

18 Downstream migrating fish, during the first half of the cycle when the lower  
valve is closed and the upper valve opens allowing water to surge through the top-half  
20 of the connection tube, down through the fish screen, and into the working tube,  
simply drift with the current down to the fish screen. After arriving at the fish screen,  
22 the fish pass to the lower half of the connection tube, which during the first half of the  
cycle is still and has no motion. Fish that did not pass the fish screen before the  
24 working tube crests will then be forced back up the connection tube towards the upper

2 valve as the falling level in the working tube will cause surging water to move back  
up the connection tube. This back and forth motion will occur as long as the motion  
4 in the working tube is not stopped by closing the upper valve. Once the upper valve  
is closed the motion will cease. Next, the second half of the cycle begins as the lower  
6 valve is opened. Water from the working tube will surge out of the working tube, out  
through the fish screen and down the lower half of the connection tube and out the  
8 lower valve carrying any fish in that area along with it. The lower valve is then  
closed and the cycle can begin again.

10 Upstream migrating fish need to swim past the lower valve while it is open  
during the second half of the cycle. As fish pass through the valve and into the lower  
12 connection tube against the current, the valve closes and the current stops while the  
fish continue towards the area of the fish screen. After passing the fish screen, the fish  
14 will be either pushed back towards the fish screen area or pushed upward toward the  
upper valve depending on the motion in the working tube. The whole upstream  
16 passage should take seconds or minutes instead of the hours or days currently  
required.

18 Energy generated from the water flow in the working tube can provide  
electrical energy to operate the valves and provide for other uses. Fish may be  
20 encouraged into, through and out of the tubes by any of various effective methods,  
such as use of light, slope of the connecting tube, water flow, etc.

## 22 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a fish passage apparatus for control of water flow that  
24 facilitates fish migration between two bodies of water of different heights, including a

2 working tube that generates power in cooperation with a power generator and  
contributes to moving fish between the bodies of water.

4 FIG. 2 is a diagram showing a plurality of fish passage apparatus of FIG. 1  
connected in series.

6 FIG. 3 is a diagram showing the fish passage apparatus of FIG. 1 adapted to  
optimize power generation instead of fish migration with the water level in the  
8 working tube at the water level of the lower body of water.

FIG. 4 is a diagram showing the fish passage apparatus of FIG. 1 adapted to  
10 optimize power generation instead of fish migration with the water level in the  
working tube at the water level of the overshoot from water surging from the upper  
12 body of water.

FIG. 5 is a diagram showing the fish passage apparatus of FIG. 1 adapted to  
14 optimize power generation instead of fish migration with the water level in the  
working tube at the water level of the downward overshoot from water surging out of  
16 the working tube when the valve at the lower body of water is opened quickly.

FIG. 6 is a diagram showing a plurality of power generators of FIG. 3  
18 connected in series.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 As shown in FIG. 1, the fish passage apparatus 10 of the present invention for  
fish passage between water bodies 12, 14 of different heights with different water  
22 levels 16, 18 comprises a connecting tube 20 providing fluid communication between  
upper and lower water bodies 12, 14, an upper valve 22 in the connecting tube 20  
24 adapted to control flow of water to or from the upper water body 12, a lower valve 24

2 in the connecting tube 20 adapted to control flow of water to or from the lower water  
body 14, and a working tube 26 containing a column of water 28 with a surface level  
4 38 opening into the connecting tube 20 between the upper and lower valves 22, 24 a  
working portion of which working tube 26 extends functionally vertical to above the  
6 water level 16 of the upper water body 12 and to below the water level 18 of the  
lower water body 14 and is vented at its top such that water can flow freely in and out  
8 of the working tube 26. A screen 30 covers the opening 32 of the working tube 26 at  
the junction of tubes 20, 26 such that fish are prevented from leaving connection tube  
10 20 and entering the working tube 26.

When the upper valve 22 is opened with the lower valve 24 closed, water  
12 flows through the connecting tube 20 and flows into the working tube 26 raising the  
surface level 38 of the water column 28 to at least the water level 16 of the upper  
14 body of water 12 and allows for fish to enter the connecting tube 20 from the upper  
body of water 12. When the upper valve 22 then closes and the lower valve 24 opens,  
16 fish may flow with the current from the connecting tube 20 into the lower body of  
water 14 as the surface level 38 of the water column 28 in the working tube 26 lowers  
18 to at least the water level 18 of the lower body of water 14. Whereupon, the lower  
valve 24 closes and a new cycle can begin again with the opening of upper valve 22.

20 An electrical power generator 34 operates in cooperation with the working  
tube 26, adapted to extract potential energy from the column of water 28 in the  
22 working tube 26 as the upper and lower valves 22, 24 are suitably operated; which,  
for example of a traditional generator, as the column of water 28 falls when the upper  
24 valve 22 is closed while the lower valve 24 is opened, or but also alternatively when

2 the upper valve 22 is opened while the lower valve 24 is closed and the column of  
water 28 rises.

4 Clearly, a plurality of said fish passage apparatus 10 may be combined in  
series where an upper body of water 12 of one of said plurality of fish passage  
6 apparatus 10 is a lower body of water 14 of a next higher fish passage apparatus until  
the final upper body of water 12 is reached, as shown in FIG. 2.

8 As shown in FIG. 3, the power generator 34 may be used without  
consideration for fish migration between the two bodies of water, that is, with or  
10 without accommodations for fish migration, the primary difference being the rate at  
which the valves 22, 24 open and close and the slope of the connecting tube 20. For  
12 power generation, the surface level 38 of the column of water 28, or head, may be  
maximized. To maximize the head in the column of water 28, the upper valve 22 is  
14 such as can be opened sufficiently quickly to result in a surge of water into the  
working tube 26 such that momentum in said surge of water results in a surface level  
16 38 of the column of water 28 in the working tube 26 that extends upward typically  
beyond a water level 16 of the upper body of water 12. Similarly, the upper valve 22  
18 is such as may be closed sufficiently quickly to capture and maintain the column of  
water 28 in the working tube 26 at a desired upper level 36, as shown in FIG. 4. As  
20 with the upper valve 22, the lower valve 24 is such as may be closed sufficiently  
quickly to capture and maintain the column of water 28 in the working tube 26 at a  
22 desired lower level 40 after the lower valve 24 is opened with the upper valve 22  
closed resulting in a surge of water out of the working tube 26, which desired lower

2 level 40 may be below the water level 18 of the lower body of water 14, as shown in  
FIG. 5.

4 As shown in FIG. 6, as with the fish passage apparatus configuration, a  
plurality of said power generators also may be combined in series where an upper  
6 body of water 12 of one of said plurality of power generators 34 is a lower body of  
water 14 of a next higher power generator until the final upper body of water 12 is  
8 reached.

In use then, electrical power may be generated from potential energy between  
10 upper and lower bodies of water 12, 14 and maximized by providing the  
configuration described above and appropriately quickly opening and closing the  
12 upper and lower valves 22, 24 to create and exploit momentum of water flowing into  
and out of the working tube 26. The cycle of opening and closing the valves 22, 24 as  
14 described is then repeated for continual power generation. Power generated may be  
used to operate the valves and for other purposes. When the configuration is  
16 additionally, or solely, used for fish migration between the bodies of water, the speed  
of the opening and closing of the valves may be reduced to prevent injury to the fish.

18

2

## CLAIMS

Having described the invention, what is claimed is as follows:

- 4 1. A fish passage apparatus for fish passage between water bodies of different  
heights, comprising,
- 6 a connecting tube providing fluid communication between upper and lower  
water bodies,
- 8 an upper valve in the connecting tube adapted to control flow of water to or  
from an upper water body,
- 10 a lower valve in the connecting tube adapted to control flow of water to or  
from a lower water body,
- 12 a working tube opening into the connecting tube between the upper and lower  
valves a working portion of which extends functionally vertical to above a  
14 water level of the upper body of water and to below a water level of the  
lower body and is vented at its top such that water can flow freely in and  
16 out of the working portion.
2. The fish passage apparatus of claim 1 wherein fish are prevented from entering  
18 the working tube from the connecting tube.
3. The fish passage apparatus of claim 1 wherein with the lower valve closed, when  
20 the upper valve is opened water flows through the connecting and working tubes  
raising the water surface level in the working tube to at least the water level of the  
22 upper body of water and fish can enter and exit the connecting tube from the  
upper body of water while the upper valve is open, and when the upper valve then  
24 closes and the lower valve opens, fish may enter and exit the connecting tube

- 2 through the lower valve as the water in the working tube lowers to a water level of  
at least that of the lower body of water.
- 4 4. The fish passage apparatus of claim 1 wherein with the upper valve closed, when  
the lower valve is opened water flows out of the working tube to at least the water  
6 level of the lower body of water and fish can enter the connecting tube from the  
lower body of water and when the lower valve then closes and the upper valve  
8 opens, fish may swim upstream through and out of the connecting tube into the  
upper body of water.
- 10 5. The fish passage apparatus of claim 1 further comprising an electrical power  
generator operating in cooperation with the working tube adapted to extract  
12 potential energy from a column of water in the working tube as the column of  
water moves when the upper and lower valves are suitably operated.
- 14 6. The fish passage apparatus of claim 1 wherein the connecting tube has a slope that  
enables fish to swim up the connecting tube.
- 16 7. The fish passage apparatus of claim 1 comprising a plurality of said fish passage  
apparatus in series where an upper body of water of one of said plurality of fish  
18 passage apparatus is a lower body of water of a next higher fish passage apparatus  
until the upper body of water is reached.
- 20 8. A power generator adapted to extract potential energy between upper and lower  
bodies of water, comprising,  
22 a connecting tube providing fluid communication between upper and lower  
water bodies,

- 2 an upper valve in the connecting tube adapted to control flow of water to or  
from an upper water body, wherein the upper valve may be opened  
4 sufficiently quickly to result in a surge of water into the connecting and  
working tubes,  
6 a lower valve in the connecting tube adapted to control flow of water to or  
from a lower water body, wherein the lower valve may be opened  
8 sufficiently quickly to result in a surge of water out of the connecting and  
working tubes,  
10 a working tube opening into the connecting tube between the upper and lower  
valves a working portion of which extends functionally vertical to above a  
12 water level of the upper body of water and is vented at its top such that  
water can flow freely in and out of the working portion such that  
14 momentum in said surge of water results in a column of water in the  
working tube extending upward beyond a water level of the upper body of  
16 water when the lower and upper valves are closed and then the upper  
valve is opened, wherein the upper valve may be closed sufficiently  
18 quickly to maintain the column of water at a desired upper level,  
an electrical power generator operating in cooperation with the working tube  
20 and adapted to extract potential energy from the column of water in the  
working tube as the column of water moves when the upper and lower  
22 valves are suitably operated.
9. The power generator of claim 8 comprising a plurality of said power generators in  
24 series where an upper body of water of one of said plurality of power generators

- 2 is a lower body of water of a next higher power generator until the upper body of  
water is reached.
- 4 10. The power generator of claim 8 wherein the lower valve may be closed  
sufficiently quickly to maintain the column of water in the working tube at a  
6 desired lower level after the lower valve is opened with the upper valve closed  
resulting in a surge of water out of the working tube.
- 8 11. The power generator of claim 10 wherein the desired lower level in the working  
tube is below the water level of the lower body of water.
- 10 12. The power generator of claim 8 wherein the desired upper level in the working  
tube is above the water level of the upper body of water.
- 12 13. The method of generating electrical power from potential energy between upper  
and lower bodies of water, comprising the following steps:
- 14 a. providing a connecting tube that provides fluid communication between  
upper and lower water bodies, an upper valve in the connecting tube  
16 adapted to control flow of water to or from an upper water body, a lower  
valve in the connecting tube adapted to control flow of water to or from a  
18 lower water body, a working tube opening into the connecting tube  
between the upper and lower valves a working portion of which extends  
20 functionally vertical to above a water level of the upper body of water and  
is vented at its top such that water can flow freely in and out of the  
22 working portion, and an electrical power generator operating in  
cooperation with the working tube and adapted to extract potential energy  
24 from water flowing out of the working tube;

- 2           b. with the upper and lower valves closed, opening the upper valve  
sufficiently quickly to result in a surge of water into the connecting tube  
4           and into the working tube such that momentum in said surge of water  
results in a column of water in the working tube;
- 6           c. closing the upper valve sufficiently quickly to maintain the column of  
water at a desired upper level in the working tube;
- 8           d. with the upper valve closed, opening the lower valve to allow water to  
flow out of the working tube
- 10          e. generating electrical power in cooperation with said electrical power  
generator as water moves in the working tube;
- 12          f. closing the lower valve;
- g. repeating steps a through e.
- 14          14. The method of claim 13 wherein at step c the upper level is above that water level  
of the upper body of water.
- 16          15. The method of claim 13 wherein the lower valve is closed sufficiently quickly at  
step e to maintain the column of water in the working tube at a desired lower  
18          level.
16. The method of claim 15 wherein the lower level is below that water level of the  
20          lower body of water.
17. The method of claim 13 further comprising the step of providing a plurality of  
22          said power generators in series where an upper body of water of one of said  
plurality of power generators is a lower body of water of a next higher power  
24          generator until the upper body of water is reached.

- 2 18. The method of claim 13 including the steps of allowing fish to enter the  
connecting tube from the upper body of water and then when the upper valve  
4 closes and the lower valve opens, allowing fish to enter and leave the connecting  
tube into the lower body of water through the lower valve as water in the working  
6 tube lowers.
- 8 19. The method of claim 13 including the steps of allowing fish to enter the  
connecting tube when the upper valve is closed and the lower valve is opened  
with water draining from the working tube and then closing the lower valve and  
10 then opening the upper valve, thereby enabling fish to swim upstream through and  
out of the connecting tube and into the upper body of water.
- 12 20. The method of providing a fish passage between upper and lower bodies of water,  
comprising the following steps:
- 14 a. providing a connecting tube that provides fluid communication between  
upper and lower water bodies, an upper valve in the connecting tube  
16 adapted to control flow of water to or from an upper water body, a lower  
valve in the connecting tube adapted to control flow of water to or from a  
18 lower water body, a working tube opening into the connecting tube  
between the upper and lower valves a working portion of which extends  
20 functionally vertical to above a water level of the upper body of water and  
is vented at its top such that water can flow freely in and out of the  
22 working portion;
- 24 b. with the upper and lower valves closed, opening the upper valve  
sufficiently quickly to result in a surge of water into the connecting tube

- 2 and into the working tube such that momentum in said surge of water  
results in an oscillating column of water in the working tube and therein  
4 establishing an upper fish migration condition during which condition fish  
may swim upward through the connecting tube and into the upper body of  
6 water and fish may swim from the upper body of water into the connecting  
tube;
- 8 c. closing the upper valve to end the upper fish migration condition and  
maintain the column of water at a desired upper level in the working tube;
- 10 d. with the upper valve closed, opening the lower valve to allow water to  
flow out of the working tube with the water level in the working tube  
12 stabilizing at the water level of the lower body of water therein  
establishing a lower fish migration condition;
- 14 e. maintaining the lower fish migration condition a desired period of time to  
allow fish migrating downstream to exit the connection tube at its lower  
16 end or to allow fish migrating upstream to enter the connection tube at its  
lower end;
- 18 f. closing the lower valve;
- g. repeating steps a through f.
- 20 21. The method of claim 20 with the additional step of generating electrical power  
from the movement of the water in the working tube.
- 22 22. The method of claim 21 wherein electrical power is generated from upward  
movement of the water in the working tube or from downward movement of the  
24 water in the working tube or both.



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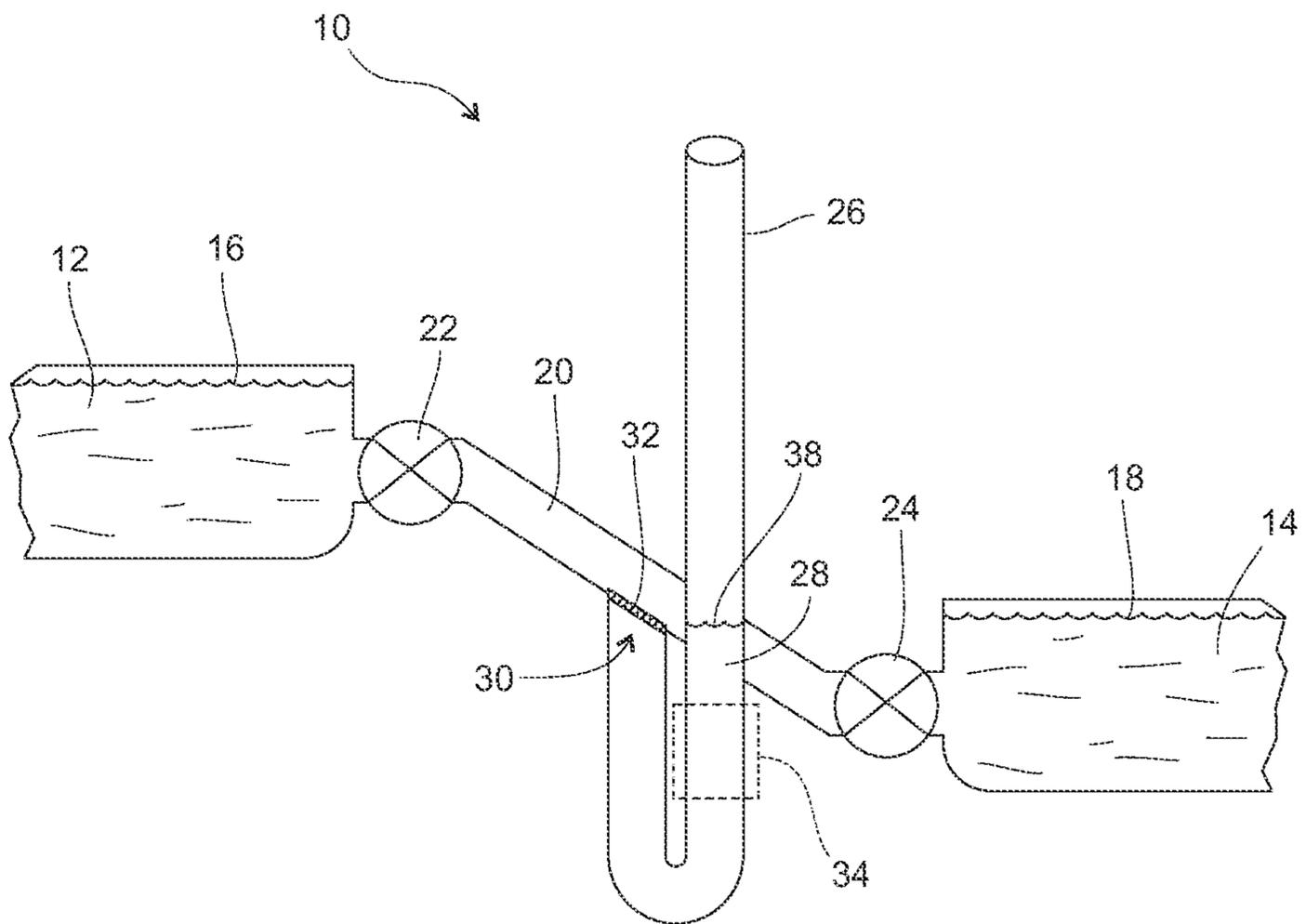


Fig. 1



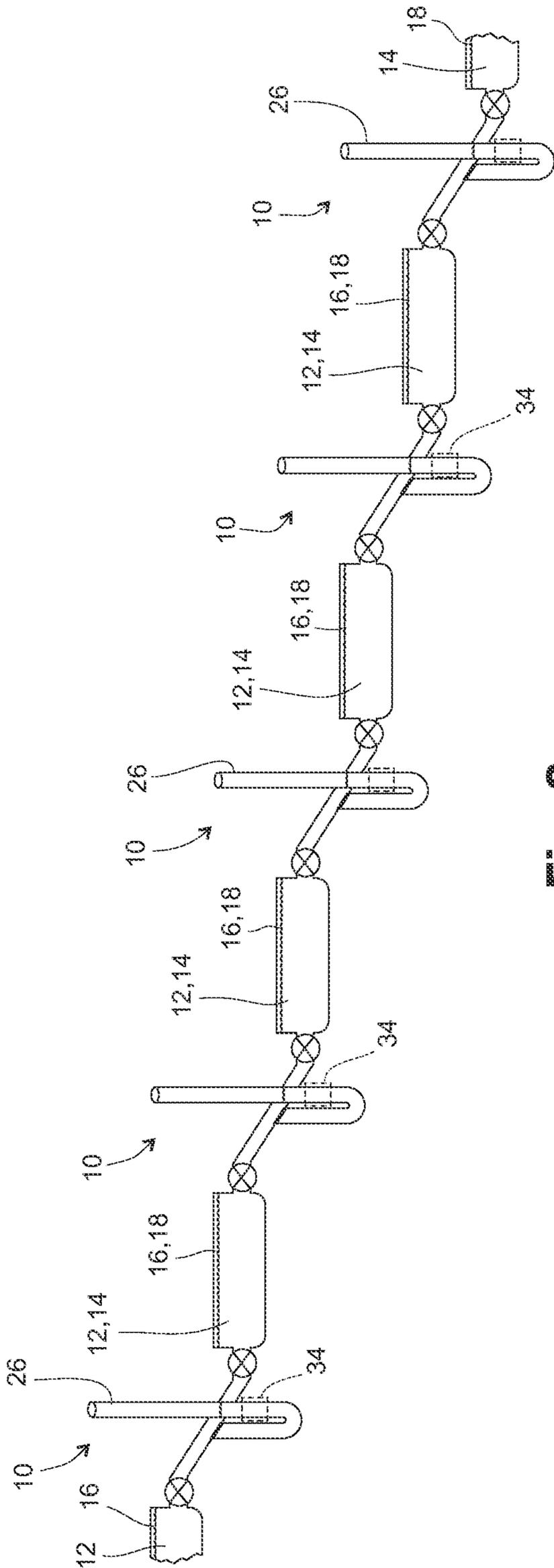


Fig. 2





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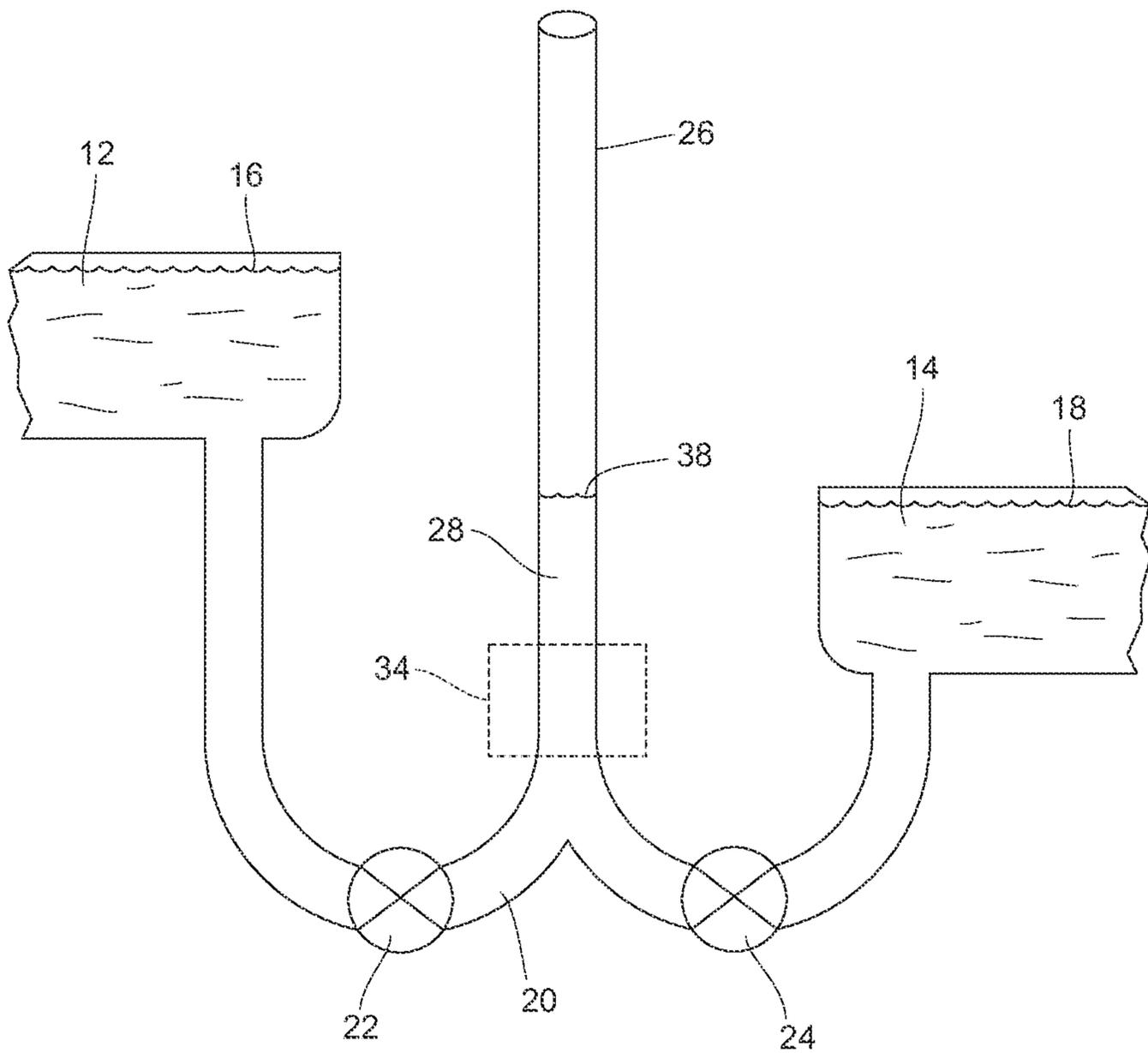


Fig. 3





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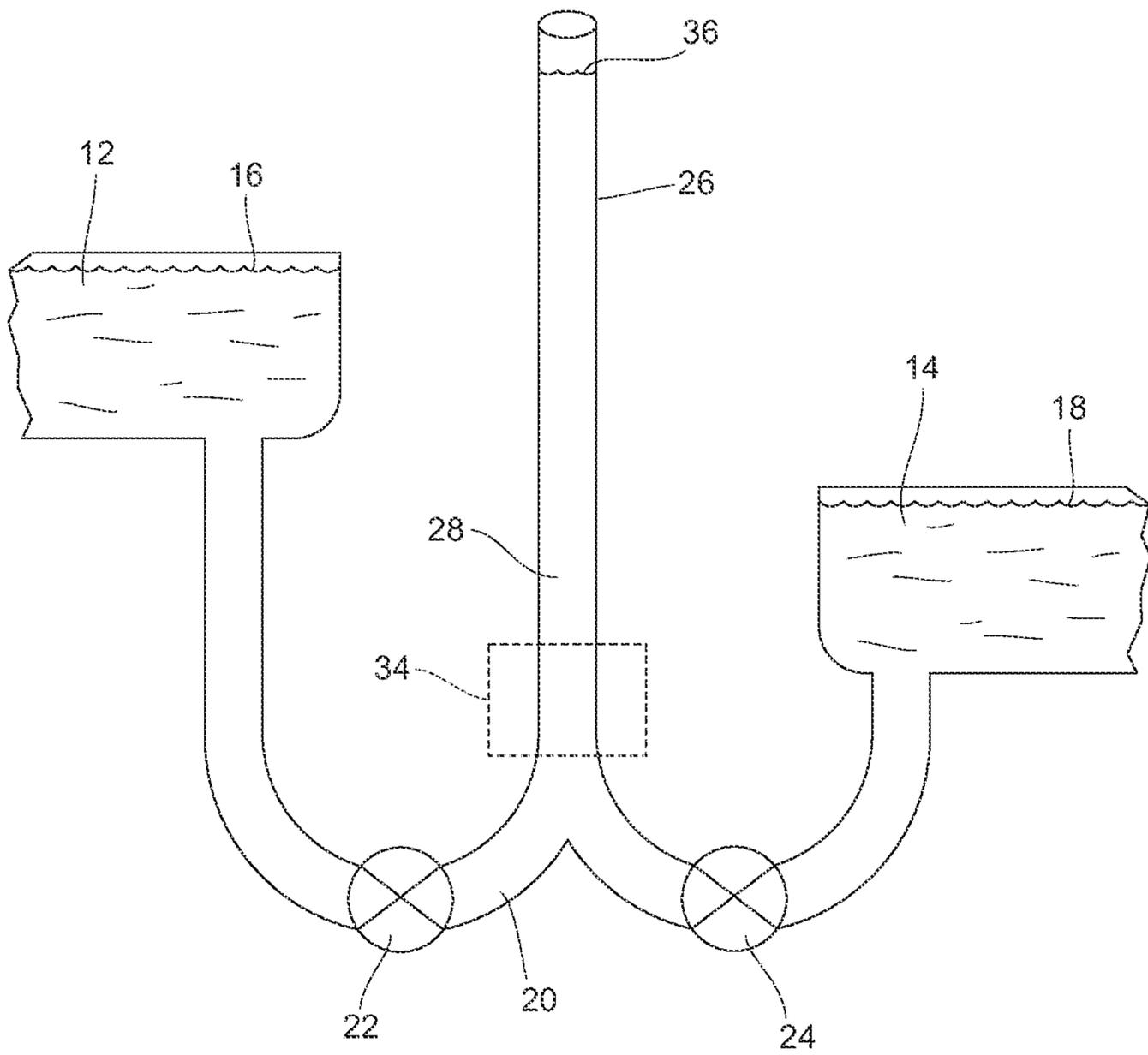


Fig. 4





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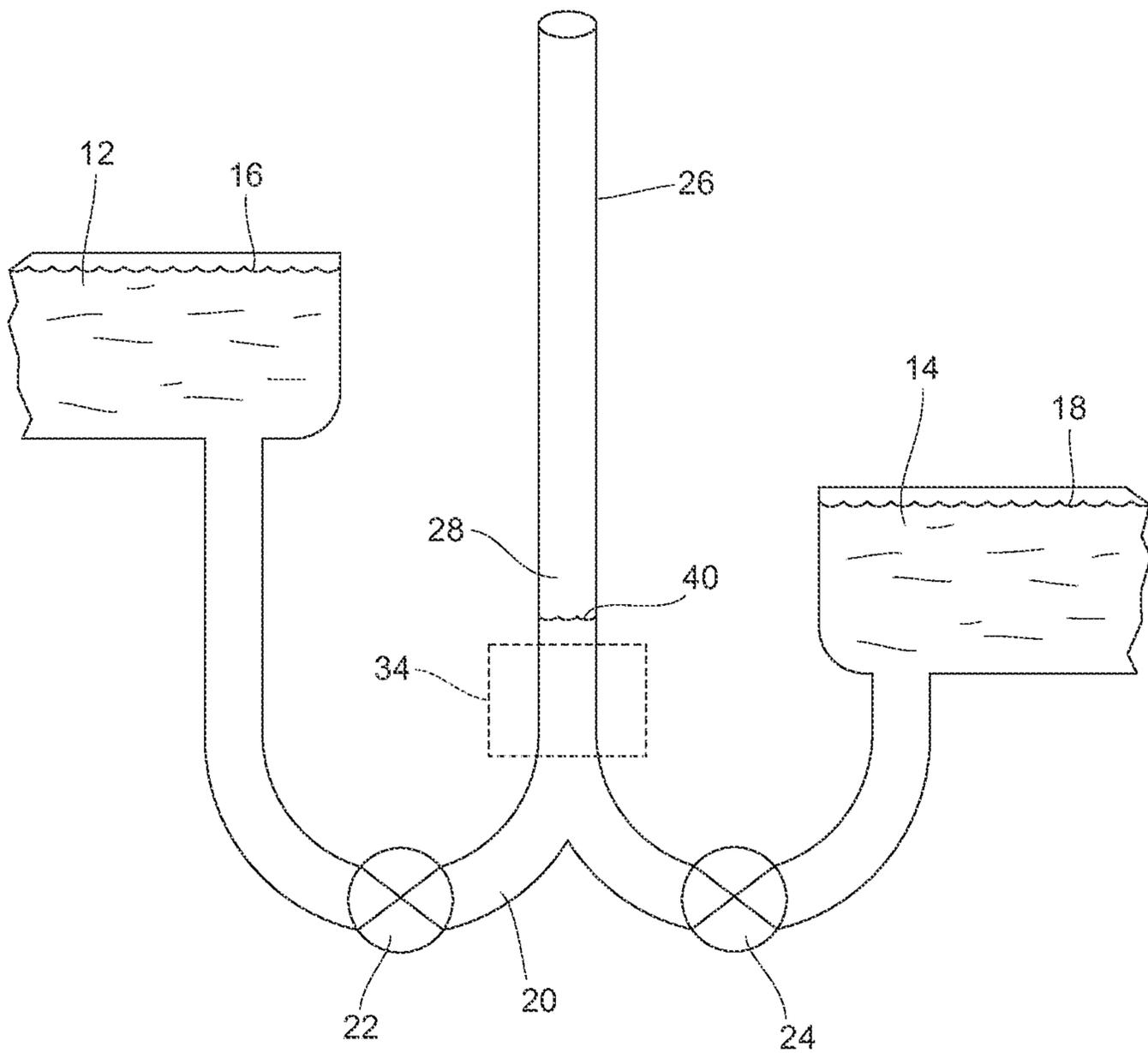


Fig. 5



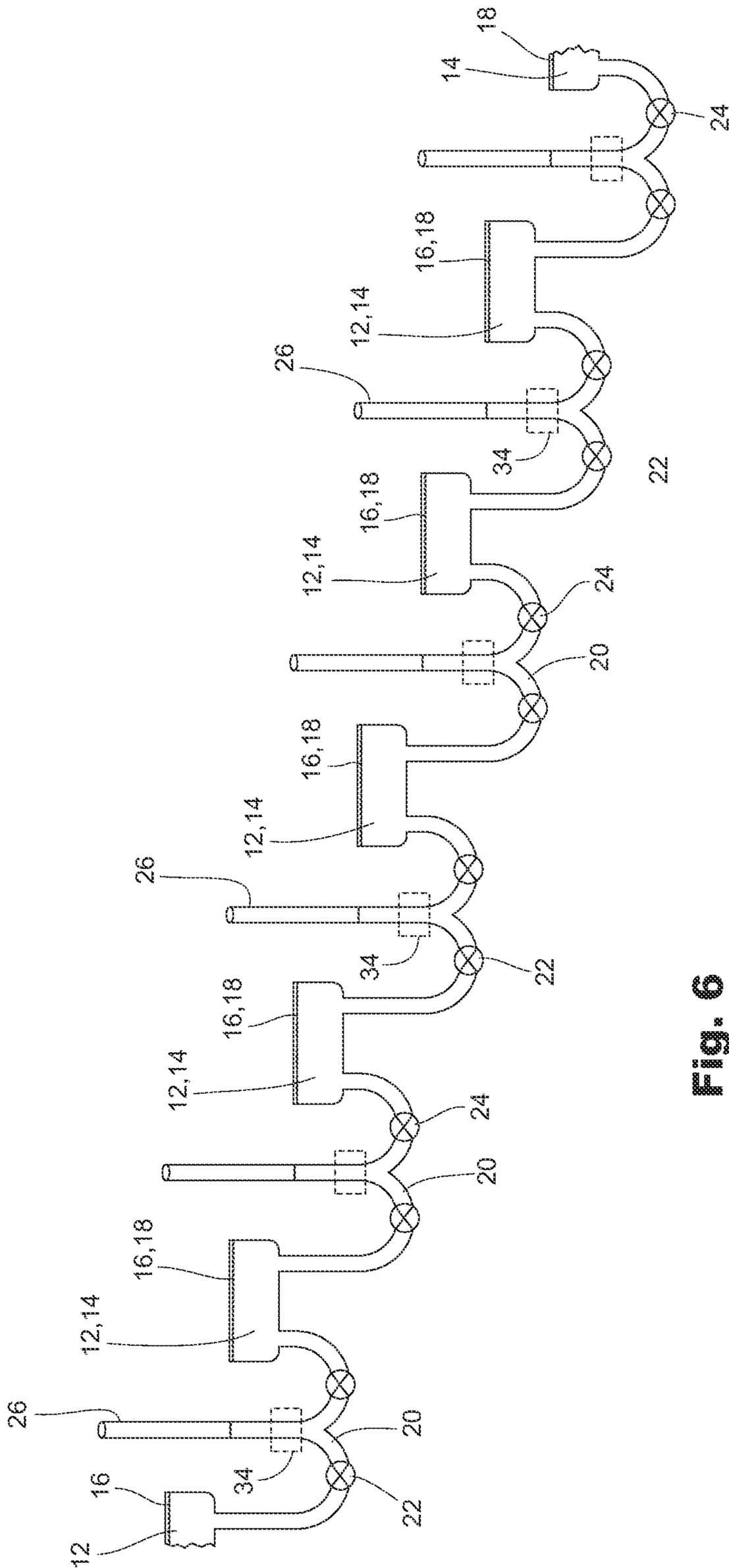


Fig. 6



