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# Pump for extremely dangerous liquids

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ABSTRACT

The pump described in this paper is based on an unusual working principle which makes it suitable for handling difficult-to-pump dangerous liquids. It is driven by a two-phase alternating air flow and in its fluidic rectifier part that comes into contact with the liquid has no moving or deformed components. It is thus leak-proof, extremely reliable, and needs no maintenance. The rectifier may be described as a series-connected array of jet-pump units with annular Coanda-effect nozzles. Each odd one of the units is connected to one phase of the driving air flow – and each even unit to the other phase. The air acts periodically on the liquid in vertical displacement tubes on top of each unit. The outflow from these tubes generates in all even jet-pump units an annular synthetic jet, attaching by the Coanda effect to curved wall that diverts it downstream, towards the pump output. At the same time in the odd jet-pump units the orientation of the nozzles makes it easy for the liquid to enter into them from upstream. An important additional pumping effect is generated by travelling waves passing through the whole array. The pump rectifier is robust and may be made of materials withstanding high temperature, chemical aggressiveness of the liquid, or special conditions like exposure to radioactivity.



*Keywords:* Pump; Jet pump; Coanda effect; Synthetic jets; Fluidic rectification

## 1. Introduction

The challenges associated with handling dangerous liquids – poisonous, chemically aggressive, or at high temperature – have been always present in chemical engineering. Also not uncommon are requirements of precise monitoring and loss prevention of even tiniest of amounts. Recent return of interest to nuclear power – to reduce greenhouse gas emissions and the dependence on politically unstable regions – increases occurrence of radioactivity in the lists of hazards. The liquids pumped in nuclear fuel re-processing: poisonous, chemically aggressive, radioactive, heat generating (in fact boiling), and strictly accounted for to avoid nuclear weapon proliferation may be an example of properties making the pumping difficult. Safety aspects demand the processing of the liquids taking place behind protective barriers, Fig. 1, in spaces of limited accessibility for personnel or no access at all. Recently the spectrum of the dangers was also widened by the pathogenic character of some of the biomaterials that are also in increasing measure handled at the rates requiring their transport by pumping. The demands on the pumps, even if handling the less dangerous ones among such liquids, are severe. They must be absolutely leak-proof and extremely reliable, requiring no maintenance. The choice of materials for manufacturing them is also limited – often to materials difficult to machine or demanding special surface character for biocompatibility.

The problem is the permanence of the separation from the outer environment. The pumps with deformed components – membranes or peristaltic tubes – may at first provide the solution, but their primary protective barrier is broken whenever these components burst, which they are likely to do because of the material fatigue. A better solution is offered no-moving-part jet pumps. Absence of any maintenance (no bearings or gaskets) is a positive advantage and the relative simple shapes permit manufacturing from non-machinable refractory materials. The components may be solidly welded together, eliminating any leakage. Unfortunately, since jet pumps operate by mixing the pumped fluid with the jet of a driving fluid, this solution results in accumulation, at the end

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**Nomenclature**

| | |
|---|---|
| A | work (J) |
| $\dot{A}$ | work done per unit time – power (W) |
| $\dot{A}_m$ | maximum available power at a given frequency (W) |
| $\bar{\dot{A}}_X$ | time-mean power input through three nozzles |
| $\bar{\dot{A}}_X$ | time-mean power input through three nozzles |
| $\bar{\dot{A}}_{X\,res}$ | time-mean power input in resonant conditions |
| $a$ | specific work done by an ideal fluid flow generator (J/kg) |
| $b$ | nozzle slit width (m) |
| C | capacitance of an active two-tube unit ($kg^2/J$) |
| $C_A$ | gravitation capacitance of one displacement pipe ($kg^2/J$) |
| $d$ | throat diameter (m) |
| Eu | Euler number (–) |
| $e$ | specific energy (J/kg) |
| $e_{kin}$ | specific kinetic energy of liquid (J/kg) |
| $\hat{e}_{kin}$ | amplitude of the specific kinetic energy |
| $\Delta e_X$ | input specific energy difference relative to vent (J/kg) |
| $\Delta e_Y$ | output specific energy difference relative to vent (J/kg) |
| $\overline{\Delta e}$ | time-mean specific energy increase in the pump (J/kg) |
| $\Delta e_X$ | instantaneous input specific energy (J/kg) |
| $\overline{\Delta e}_X$ | time-mean specific energy input in nozzle (J/kg) |
| $\overline{\Delta e}_{X\,id}$ | idealised time-mean specific energy input in nozzle (J/kg) |
| $\widehat{\Delta e}_X$ | amplitude of specific energy in nozzle (J/kg) |
| F | nozzle exit area ($m^2$) |
| $F_c$ | throat area ($m^2$) |
| $F_d$ | displacement pipe cross-section area ($m^2$) |
| $F_p$ | piston crown surface area ($m^2$) |
| $f$ | frequency (Hz) |
| $f_{res}$ | resonant frequency (Hz) |
| $g$ | gravitational acceleration ($m/s^2$) |
| $\Im$ | inertance of a pair of neighbour displacement pipes ($m^2/kg$) |
| $l$ | length (height) of liquid columns (m) |
| $\dot{M}$ | mass flow rate (kg/s) |
| $\dot{M}_X$ | input mass flow rate (kg/s) |
| $\dot{M}_Y$ | output mass flow rate (kg/s) |
| $\bar{\dot{M}}$ | time-mean pumped mass flow rate (kg/s) |
| $\bar{\dot{M}}_{nl}$ | time-mean pumped mass flow in the no-load regime (kg/s) |
| $\widehat{\dot{M}}_{X\,id}$ | amplitude of idealised mass flow rate in nozzle (kg/s) |
| $\overline{\dot{M}}_{X\,id}$ | time-mean idealised mass flow rate in three nozzles (kg/s) |
| P | pressure (Pa) |
| $\Delta P$ | pressure difference (Pa) |
| $\overline{\Delta P}$ | time-mean pressure rise in the pump (Pa) |
| $\Delta P_m$ | maximum driving pressure difference (Pa) |
| $\Delta P_s$ | supply pressure difference (Pa) |
| $P_{nf}$ | dimensionless pressure parameter (–) |
| Q | dissipance of output resistor (–) |
| $Re_d$ | output (and throat) diameter Reynolds number (–) |
| Re | nozzle exit Reynolds number (–) |
| $r$ | curvature radius of the attachment wall (m) |
| $s$ | length of column leaving the nozzle during one cycle (neglecting compressibility)(m) |
| $v$ | specific volume ($m^3/kg$) |
| $v_{at}$ | specific volume of atmospheric air ($m^3/kg$) |
| $w$ | velocity (m/s) |
| $\hat{w}$ | amplitude of harmonically varying velocity (m/s) |
| $\bar{w}$ | time-mean velocity (m/s) |
| $w_S$ | reference velocity (m/s) |
| z | piston stroke (m) |

*Greek alphabet letters*

| | |
|---|---|
| $\alpha_e$ | relative output power (–) |
| $\alpha_m$ | efficiency of rectification and power transfer (–) |
| $\eta_e$ | relative output specific energy (m) |
| $\mu_e$ | flow ratio (–) |
| $\nu$ | kinematic viscosity ($m^2/s$) |
| $\Omega_{res}$ | natural angular frequency of a two-column unit (rad/s) |

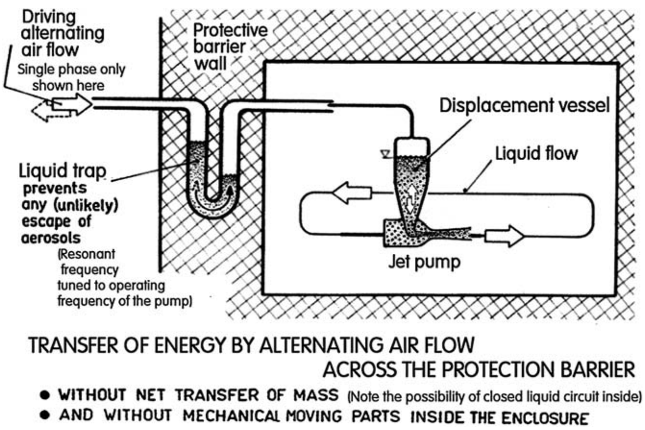


**Fig. 1 – Transfer of power by alternating air flow through the protective barrier. Together with leak-proof and maintenance-free fluidic rectification on the liquid side this brings unparalleled advantages. Of course, power may be transferred even more easily and reliably easily by an electric cable – but then it is difficult, if not impossible, to have a no-moving part pumping unit behind the barrier.**

of the process chain, of the amount of hazardous waste – in some cases offering no other choice but permanent storage in special locations.

## 2. Forward flow diverters and travelling waves

The solution described in this paper is essentially a development of the jet pump idea. Driven by zero time-mean alternating flow, the pump does not produce any addition to the final waste. Also, this character of the driving makes possible (Fig. 1) transfer of energy across the protective barrier. It may be argued that an electric cable would transfer the power there as well (and with less loss) – but it certainly would need moving components inside the enclosure.

The alternating-flow driven jet-pumping is effective, of course, only during a part of the cycle. Then follows the return phase of re-supplying the driving fluid (which is here,