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Article

Recasting Chemical Engineering to Welcome AI: AI Calibrated, Purpose Adaptable, Threaded, Universal Unit Processor

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Abstract: Chemical Engineering, in particular fluid-handling technology, is governed by transport phenomena which for practical purposes present analytically intractable mathematical equations. Optimization then is best served through the emerging tool of artificial intelligence, AI. AI is using neural network to optimize fluid control parameters in order to get a mixture of fluids to behave as wished. In order for AI to be effective, we propose to implement a complete process as a series of steps wherein each step is taken by the same type unit processor -- a universal unit processor, UUP -- over a quantum of fluid. This quantum of fluid, QoF undergoes a step-wise processing and then is moved to the next UUP for the next processing step. Each of these UUP is AI-optimized with increasing process experience. The UUP is constructed as a multi-mode piston, MMP, moving laterally, and freely rotating within an encapsulating cylinder. The multi-mode piston is drilled with holes that open and close. The combined motion of lateral movement, rotation, and hole-dynamics offers comprehensive motion management over the processed quantum of fluid. Each UUP is AI-programmed to pump fluid, mix fluid, serve as a reactor and a separator. The UUP are strung in series and in parallel to move the raw material to the final products. Eventually the UUP will be AI-threaded to complete the process. Once the power of AI is fully harnessed, the scope, efficiency and outreach of chemical engineering will be way ahead.-

Keywords: stirred tank reactor; mixing; reacting; separating; distillation; AI; Piston; chemical engineering

1. Introduction

The novelty in this article is three fold: (i) AI oriented chemical processing, (ii) universal unit processor (UUP) (iii) the multi mode piston apparatus.

Continuous flow operation has been the prevailing mode in chemical engineering since the beginning of the profession, and throughout its many applications. A dedicated control system is trained on keeping the state of the material involved in a steady state at each step of the process, with process progress recorded along the line of operation.

This continuous flow mode suffers from variability in the states as they move along the process. The continuous mode does not allow for corrections, the material front rushes along the process carrying with it all its non-conformity. This build up of "errors" can be corrected by replacing the continuous mode with a rapid succession of batch mode operation. A certain amount of fluids may be temporarily isolated from the flow, processed until the desired state is achieved, and then this amount is pushed downstream. If this interval time of isolation is made brief enough then it would leave no impact neither on the upstream, nor on the downstream.

The advantage of separating an amount of matter for focused processing is in one's ability to keep processing this amount until it reaches the egress conditions to the degree desired. Such processing might require an extended time, which in turn will require flow coordination with the upstream and downstream. If the upstream and downstream are also comprising such quantum fluid modules then it is straight forward to coordinate timing.

It is noteworthy that any such quantum processor may be fed from one or more similar processors, and feed into one or more quantum processors.

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This analysis leads to a vision of threaded quantum fluid modules, each individually controlled to optimize the step-wise process expected of that module.

2. AI Oriented Chemical Processing

The biggest hurdle for optimality in fluid handling operation is the complexity of transport phenomena which are mathematically too complex to be solved for actual operational challenge. This is a perfect working ground for AI, using neural network to hunt for optimality in handling a mixture of fluid in an entrance state and transforming the mix into an exit state.

For AI to work well it requires a fixed configuration for the relevant factors. This calls for using a standard universal unit operation to handle all fluid handling tasks. AI will then maximize its conclusion extraction capability.

Accordingly, we define a universal unit operator, UUP, which originally is described only through its functionality. It is an apparatus that accepts an arbitrary number of inlet fluids, and releases an arbitrary number of outlet fluids. The UUP is essentially a fluid container with internal moving parts. It has the means to suck the inlet fluids into itself, encapsulate a quantum of these fluids, and separate it from the outside. Once captured the quantum of fluid, QoF, is being measured with sensors. The reading is past to an associated control unit where operational algorithms evaluate the readings and then send out control signals to kinetic elements in the UUP that impact momentum, mass, and energy transfer onto the captured quantum of fluid. This motion of the QoF continues until by measurement or by judgement the quantum of fluid is in the planned exit state and ready to be pushed out of the UUP capsule onto the next UUP or onto a line up of next UUP, or to the its final disposition. When the quantum of fluid is pushed out, it in parallel sucks in the next quantum of fluid, to apply on it the same process.

The issue of optimization comes to the fore with the algorithms that take in the measurements of the QoF in the UUP and decide on a control strategy relevant to all the degrees of freedom for the UUP objective.

It is here in the relationship between the control strategy for the degrees of freedom for the UUP and the gap between the entrance state and the exit state that AI offers its contribution. The UUP control system is managed by a super control module of AI in which randomized changes in control parameters are tried, measured, evaluated and finally improved upon.

Because all UUP share apparatus-similarity then all the individual UUP-AI units are interrelated, exposing common pattern. The more similar the UUP, the more conclusion potential will be extracted from them. This is the profound motivator to use a single structure UUP for all the unit operations that today are individually designed. See Figures 1 and 2.

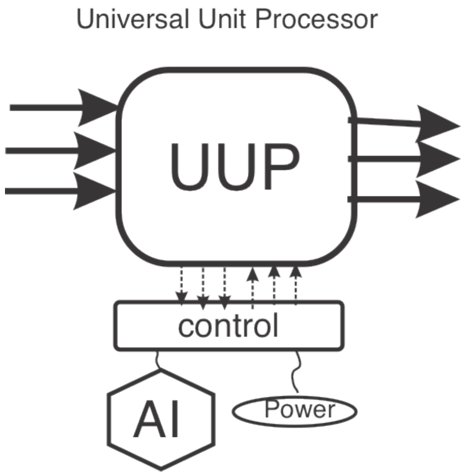

Figure 1. Universal Unit Processor.

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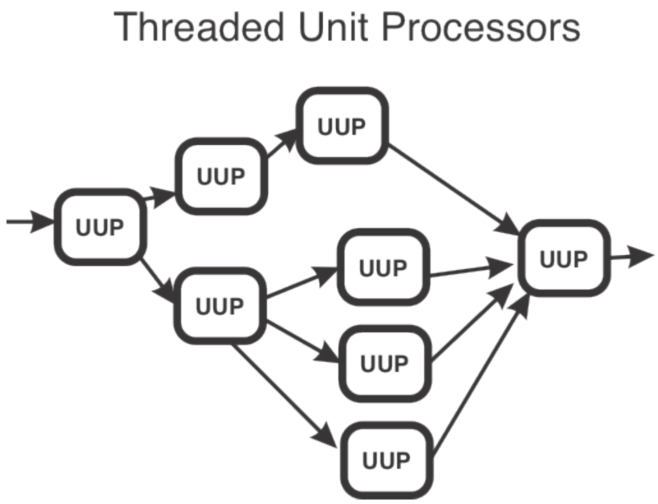

Figure 2. Threaded Unit Processors.

3. Universal Unit Processor (UUP)

Presenting the idea of quantum fluid processing, and describing the mult-mode piston as a way to implement it.

3.1. Quantum Fluid Operation

The most recognizable staple of chemical engineering since the inception of the profession is the continuous stirred tank reactor. It has done a good job by and large and has been improved plenty. Alas its process is continuous. Material flows into the tank and emerges out of the tank at a variable rate.$_t$ On average any element of matter spends a time T_r in the reactor. "On average" -- that means that some matter spends much less time than T_r and some much more. It means that the mixer often mixes material with itself and undermixes other parts. It means that the uniformity of the emerging product is wanting. The larger the reactor, the more serious the problem. It can be alleviated by change of size, and geometry. Alas the process variance is inherent in the continuous operation.

Come to think about it, any continues operation with a material flow at a rate of F_t may be matched by a quantum approach where a quantum of fluid Q is taken up by a quantum processing module, QPM -- treated batch-wise to move Q from some given (ingress) conditions Q_i to a subsequent condition (egress) Q_{i+1}. Let T_{in} be the time it takes for the quantum processing module to draw in the quantum of fluid, and let T_p be the time it takes the QPM to carry out what we will call the "payload operation" -- effecting the change Q_i to Q_{i+}And let T_{out} be the time it takes for the QPM to discharge Q from within the module.

If we set these values to obey the following relationship:

$F_t = Q / (T_{in} + T_p + T_{out})$

then from the point of view of an observer from outside the operation there will be no difference between the former continuous operation and the new quantum operation: both the upstream and the downstream will be blind to the switch from continuous mode to quantum mode.

Since all the four parameters in the right side of the equation are degrees of freedom, then there is no difficulty to exchange the continuous operation with quantum operation.

3.2. The Question is Then -- What Is the Benefit of the Quantum Approach?

We start with uniformity. The captured quantum can be treated until done. Every part of the quantum is subjected to whatever the Quantum Processing does for as long as it does it. This modus operandi gets rid of the time-spent variance experienced in the stirred tank reactor.

The entire sequence of continuous operation can then be replaced with a series of QPM modules, each advancing the state of the raw materials towards the final outcome.

What is left is to find such a module. And with a bit sense of ambition and hutzpah we may even seek a standard structure QFM which will be adjustable to the task at hand.

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In chemical engineering we pump, we mix, we react and we separate -- can a single structure module take care of all the above?

The essence of what we do in chemical engineering, when it comes to fluid is that we move the fluid with maximum degrees of freedom. Hence the standard module we are seeking will have to be equipped to move fluid full range. Assuming the QPM will have a container, call it a capsule, where to capture the quantum of fluid, we may think of internal parts that can move fluid in all three dimensions and furthermore change the flow regimen on the spectrum between laminar flow to turbulent flow.

3.3. Multi-Mode Piston

What is the simplest way to move fluid in a given direction? A piston fitted in the container, a capsule, with. a degree of freedom to move back and forth along a given direction, say the longest dimension. Now we need to take care of movement in the other two directions. It takes a small spark to suggest drilling holes in the piston and allowing each hole to be either covered (closed) or uncovered (open). Moving a holes-drilled piston in a closed container will impress momentum on the fluid in the direction of the drilled holes. If a hole is built in an inclined direction towards the direction of movement of the piston then when the piston moves while the hole is open, then it forces fluid to flow through the hole in the inclined direction, which is off the main direction handled by the piston. Now if we add to this piston with holes the freedom to rotate around the main direction of piston movement then we achieve the ability to generate planned flow in all three directions. If the piston does not rotate and large holes are open then the movement of the piston will generate a laminar flow. If on the other hand the piston will rotate and fast, and some holes are open, while the rest are closed, then a movement back and forth of the rotating piston will generate a turbulent flow.

The figure below depicts how two streams emerging from cross inclined holes in the piston are getting thoroughly mixed:

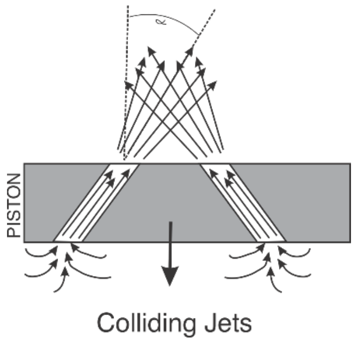

Figure 3. Colliding Jets.

The table below describes the open/closed states ("O"-open, "X" - closed) of the holes in P_{in}, and P_{out} the two stationary pistons (edges) of the capsule and the slider piston for the multi-mode piston (MMP) unit basic version:

Table 1. MMPub open/closed States of Pistons.

MMPUb open/closed states of Pistons			
	Pin	Slider	Pout
loading	O	X	O
Payload	X	O	X
Discharge	O	X	O

The quantum fluid dynamics is shown relative to four successive quanta of fluids:

Table 2. Quantum Fluid Dynamics.

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Quantum Fluid Dynamics					
time	Upstream	Loading	Payload	Discharge	Downstream
Δt	1				
Δt	2	1			
Δt	2		1		
Δt	2		1		
Δt	2		1		
Δt	3	2		1	
Δt	3		2		1
Δt	3		2		
Δt	3		2		
Δt	4	3		2	
Δt	4		3		2
Δt	4		3		
Δt	4		3		
Δt		4		3	
Δt			4		3

In summary, a rotating piston drilled with fluid pass way holes, while moving from one edge of the capsule to the other, will create any desired flow pattern in the captured quantum of fluid.

The figure below shows (4) a piston that moves inside its capsule with a cogwheel fitting, operated with a built-in rechargeable battery. It has an internal rotating disc with holes that may be open or closed. The figure on the left (5) shows an MMP designed for high viscosity fluids, requiring hydraulic operation.

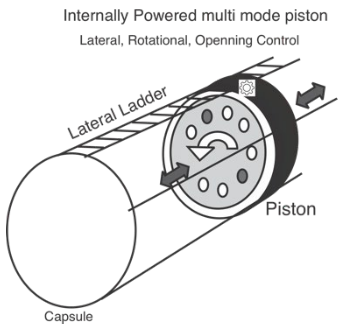

Figure 4. Internally Powered Multi-Mode Piston.

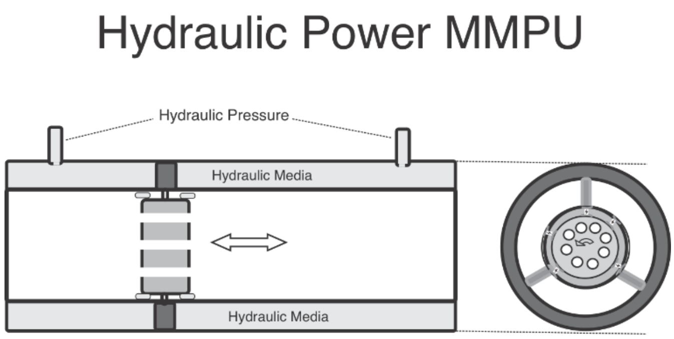

Figure 5. Hydraulic Power MMPU.

Let's see what we have so far. This capsule with the holes-drilled rotating piston inside can readily accomplish pumping. First, it sucks in fluid as its holes are closed. The the piston moves back to the edge of the cylinder where the fluid was pumped in from. It does so with all its holes open and the inlet closed. The liquid then has no choice but to flow past the returning piston to the other side of the capsule. Once at the edge, the piston holes are being closed and the piston moves away from the entry edge, pushing the captured quantum of fluid outside the capsule, all the while sucking in the next quantum, and so quantum after quantum the QPM is pumping the fluid forward. Let the capsule be fitted in a pipeline and this creates an in-pipe pump, which may be run on an internal chargeable battery, or on electrical grid, or on steam, or on a combustion engine, or on hydraulics. This in-pipe or in tube-pump works is applicable over a wide range of sizes.

The rotation of the moving piston with some holes open achieves a desired degree of mixing and unlike the situation with the stirred tank, all the parts of the quantum of fluid undergo the same

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processing and end up in the same degree of mixing. A fluid-to-fluid reaction depends on the degree of mixing, so the QPM is good for pumping, mixing and fluid-to-fluid reaction.

The figure below (6) shows a piston comprising eight independently moving discs that can be arranged to project a closed piston, a fully open piston, and anything in between.

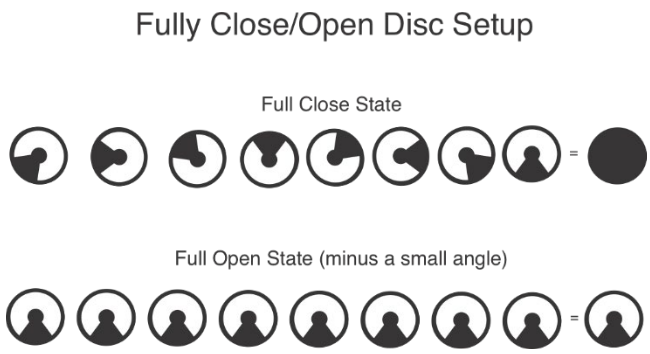

Figure 6. Fully Close/Open Disc SetUp.

Let's move to separation. Let the quantum of fluid be comprised of two mutually immiscible liquids one H heavier than the other, L. Let some ingredient X be present in L and not present much in H, while the process operator wishes X to change residence to H. The QPM will get L and H to mix and develop a large contact surface between L and H (that what mixing means), X will then migrate from L to H. (If some heat exchange is needed, so be it). Once X migrated to the planned degree from L to H, the capsule can be positioned vertically, allowing gravity to push H down and L up. The piston will move holes-open to the border line between L and H then close the holes and move L and H apart. Mission accomplished. The same trick may be applied to distillation -- the pump is placed on the border area between the liquid phase and the gaseous phase and separation is carried out.

A host of separation processes is based on "flow impact media" -- a certain solid media that creates a discriminating force like in chromatography. The Flow Impact Media, FIM, is also appreciated in a catalytic environment. One can then place the FIM in the inner linings of the holes in the piston, or as a membrane in some holes, through which the fluid is forced to pass and rub against the FIM.

So now we list pumping, mixing, reacting and separating -- all carried out via a QPM comprising a capsule and holes-drilled rotating and straight moving piston: a multi mode piston. (MMP).

Other more efficient QFM will be found down the road. But for now we regard the multi mode piston unit MMP unit (MMPU) as an effective quantum processor module.

We can see several advantages,

The vision so far is a series of MMP units hooked together such that the output from one is the input of the other. If needed, a capsule feeds to two or more capsules (MMP units), and if needed two or more capsules feed into a single MMP unit and all together we see the MMP unit as a building block for a full-fledged chemical process.

Here below (7) is a depiction of two MMP units hooked together. They are of different diameter but of the same internal volume so that a quantum of fluid from either unit fits into the other. On the right, (8) a division and compound MMP configuration is shown.

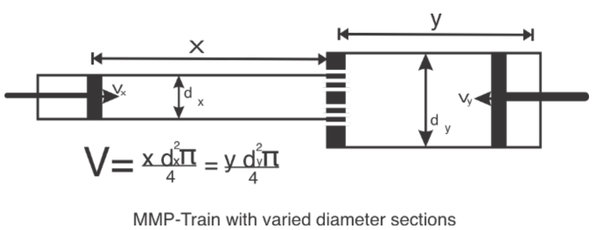

Figure 7. MMP Train with varied diameter sections.

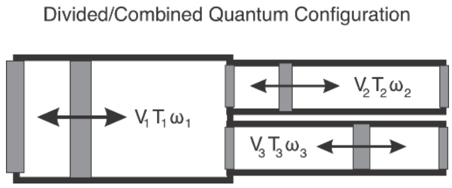

Figure 8. Divided/Combined Quantum Configuration.

The MMP units are assembled together "Lego like" (Fig 9) to represent any a complex fluid processing sequence:

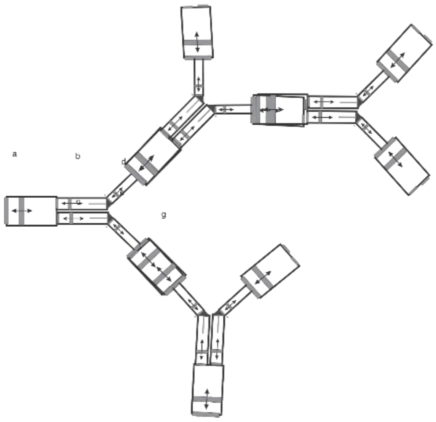

Figure 9. Lego Construction.

Every MMP unit is fully defined by specifying the position of the piston along its direction of motion, by specifying its rotational state and by specifying the open/close state of all the holes in the piston. This is a time dependent tuple that describes the state of the MMP unit over time. This dynamic tuple defines the applied control strategy. It is perfect raw material for inferential AI neural networks.

The hooked-up MMPs can fit in a tight place and lead to compact production units that are fully automated and hence can be operated by unskilled operators. See figure below (10)

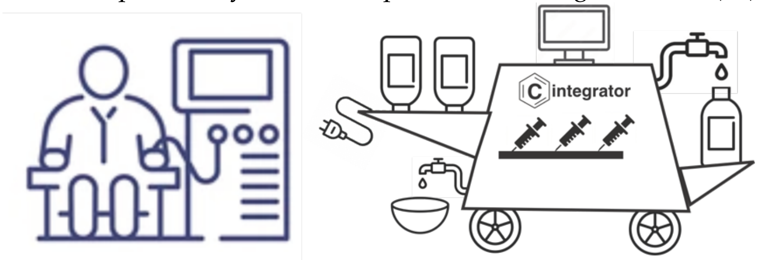

Figure 10. Integrator.

We learn from AI techniques that the greater the relational similarities between remote elements the greater the inferential output thereto. Thus, the universal structure of the multi mode piston unit that is kept through changes in tasks from pumping, mixing, reacting and separating, the more AI wisdom is expected.

In particular, a chemical process with a required output of Z (barrels/day) can be accomplished by constricting n production lines, each put together from hooked-up MMP units, and each with a production capacity of Z/(n-2) barrels/day. This will allow one to run (n-2) production lines in parallel so that together they satisfy the Z production rate requirement. Two production lines are left idle. One line is taken up for routine maintenance, and the other production line is taken up for upgrading options. The n production lines rotate.

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The planners of the production line come up with a strategy S to meet the processing challenge. This strategy is expressed through a table that lists all the values of the operational parameters of the all the MMP units, namely the piston shift position, the piston rotational position, and the states of the holes of the piston.

This digital expression of the production strategy may then be subject to small enough randomized modifications, which in turn create a distinction in production efficiency among the (n-2) production lines. These distinctions are exactly what a standard supervised AI algorithm will need to apply a neural network or equivalent methodology to seek a better and more optimized production strategy.

Unlike customary optimization which is done once and then applied again and again. The strategy described here is dynamic, it keeps changing the recommended optimum, following any de facto changes in the attributes of the raw materials or in the exact requirements of the product, or any new regulations for disposing off the refuse.

The MMP unit can be further optimized per its dimensions. The smaller the diameter of the capsule and the longer the cylinder, the greater the ratio between outside surface to volume, and that implies easier possibilities to apply heat exchange contraptions, or to inject additives, or to fit all sorts of analytics onto the surface. On the counter side, the smaller the diameter the more difficult it is to achieve the desired mixing state. The latter can be compensated by increasing the per capsule processing time, allowing the piston to move back and forth more times to achieve the desired mixing. All these related parameters are subject to optimization.

3.4. MMP Construction Technology

If indeed the MMP units become universal then they will attract very serious design efforts which will result in very efficient, durable, and reusable constructions. There are various options how to get the piston moving. It can be done with the traditional rod, it can be hooked to a hydraulic surface. It can be operated through a built-in rechargeable battery, which is the most convenient, for situations where the required force is limited.

The piston can slide inside the capsule, it can roll, it can move along through cogwheels. It all depends on the size, the required force and the required speed of moving back and forth. Expectedly, different solutions for different tasks.

The main motion axis of the piston is where most of the power is required. Much less for rotation and even less for changing the open/close state of the holes.

Changing open/closed state of holes can be done through a rotating cover, or through a pack of discs that rotate against each other. The discs will have holes in them. When some holes are aligned, fluid goes through, when they are totally off, no passage of fluid occurs.

Various applications will call for different holes in terms of numbers, location, size and shape. For separation and catalytic purposes, the width of the piston will play a role. The inner linings of the holes will be fitted with fluid-impact media and the wider the piston the more the passing fluid touches this media.

3.5. A Formal Presentation of the Multi-Mode Piston Unit

Presenting a generic multi-purpose fluid handling dynamic apparatus, a multi-mode piston, MMP, built as a piston moving in direction perpendicular to its surface (lateral movement), the piston is of an arbitrary shape, it is constructed as an external ring that envelops an internal circular part of the piston, a 'disc pack'; the disc pack is independently rotating around the axis of the piston's motion. Alternatively, the piston is circular and without a ring, comprising only a disc pack.

The rotating part of the piston is constructed with holes (fluid passageways) through its surface, where each hole can be of an arbitrary size and arbitrary location, and each hole may independently switch its state between fully open, partially open, and closed; and where at any moment in time the piston may be at a certain lateral position, a certain rotational state, and each of its holes is in a certain state in the open/closed range.

Fluid that flows through the opened holes of the pistons is undergoing a desired process. This piston is controlled by an MMP controller (MMPC) that determines the values of the degrees of freedom of the MMP: lateral position, L(t), rotational position, R(t), and open states, O(t) of its holes (fluid passageways) throughout a range of time t from a preset T_{start} to a preset T_{finish}.

The width of the MMP, *w*, is arbitrary. In certain embodiments the inner walls of the holes are lined up with fluid-impact media, FIM, that changes certain attributes of the passing fluid. The holes are either empty or stuffed with a fluid-impact porous media; fluid impact is exemplified by the following partial list: (i) catalysis of a chemical reaction within the fluid, (ii) reaction between the fluid and the fluid-impact media, (iii) separation between ingredients within the fluid.

The MMP may be moved laterally with a rod perpendicular to its surface and where the rod is being moved along its axis through an external power source, and where the rod is rotated with an external power source, and this rotation rotates the piston attached to the rod.

The holes in the MMP are generated by either:

(i) constructing the disc pack as a pack of adjacent discs with holes in them, where the discs rotate independently so that they are configured for (i.i) a state of no overlap between the holes of the discs, which is a state of "closed" for the piston, or (i.ii) the discs are configured to create full overlap among the holes of the discs, which is the state of "fully open" for the piston. In a third option (i.iii) the discs are configured with a partial overlap among the holes of the discs. This is the "partially open" state. The degree of the state of being open is determined by the degree of overlap among the discs of the pack.

The mutually adjacent discs receive rotation power by either one of the following ways:

(i.a) each disc is attached to a rotating rod, where the rods of the adjacent discs are concentric, each with a different diameter, and each is rotated individually through a power source outside the MMP;

(i.b) an internal battery which is charged either by wire or wirelessly;

(ii) constructing the disc pack with a pivot next to each hole, the pivot secures a hole-shaped plate, a "rotating cover", that may be aligned with the hole and cover it completely, or may be rotated away from the hole and open it completely, or it may be placed to partially overlap the hole and keep it partially open, the rotating covers are powered by an internal battery.

Alternatively, the discs are connected to concentric rods so that each concentric rod can be independently rotated in order to achieve the desired state of overlapping among the holes of the discs.

Pumping:

In-line Pumping is done through the following steps:

(i) the MMP is put in a 'closed' position with respect to all its holes.

(ii) the MMP is moved inside the pipe with the fluid to be pumped. The movement is in the direction of the pumping, from a starting position P_{start} to a finish position P_{finish}, thereby pushing forward the fluid ahead of it, and sucking towards it the fluid behind it.

(iii) the MMP is switching to fully open states for all its holes.

(iv) the MMP is moving back from point P_{finish} to point P_{start}, while the fluid ahead of it flows through its holes to behind the MMP.

This sequence repeats for as long as it is desired to keep the pumping operation of the MMP.

Mixing

Mixing is carried out as follows: let a quantum of fluid be sucked in from the left circular edge of the cylinder, and be pumped out from the right circular edge of the cylinder, when the quantum of fluid is fully sucked into the capsule the following steps are carried out:

(i) both edges (stationary MMPs) are set into "closed" state

(ii) the moving MMP is positioned abreast of the right edge, and is set to "open" state

(iii) the moving MMP is moving right to left while rotating thereby mixing the quantum of fluid in the capsule. When the moving piston arrives at the left edge, it reverses cours and returns to the right edge, to finish one out of several cycles that are practiced until the quantum of fluid in the capsule is mixed to a desired degree. When the state of desired mixing has been achieved the moving

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piston is positioned abreast of the left edge of the cylinder, switches to fully closed state while the two stationary pistons (the edges of the capsule) switch to open state; the piston then moves to the right edge thereby pushing out the quantum of fluid inside the capsule, and sucking in a new quantum of fluid, to be mixed as the former one was, so continuing as long as fluid is available as input.

Reactions

Using the MMP to carry out in-fluid chemical reactions one would be applying any necessary heat-exchange apparatus around the capsule, and as necessary inject into the capsule any required additives. The movement back and forth of the MMP will continue until the desired reactions achieved their designated status.

Separation

To satisfy a need for separation between two constituents A and B within a fluid, where the separation is effected through a fluid-impact media which discriminates between A and B, A being attracted to the fluid-impact media, B being rejected by the fluid impact media, the moving MMP is creating a fluid flow in contact with the fluid-impact media such that fluid that emerged from behind the moving MMP is richer with constituent A and the fluid that is ahead of the moving MMP is richer with constituent B, thereby there exists a point x between the right edge of the capsule, E_r, and the left edge of the capsule E_l where the fluid between the MMP and E_l is optimally richer with constituent A and the fluid between x and E_r is optimally richer with constituent B, the two parts of the quantum of fluid are then routed to different destinations where each part can separately undergo the same separation procedure. This sequence is repeated an arbitrary number of times to achieve an arbitrary level of separation between constituents A and B.

An arbitrary number s of holes in the MMP is fitted with the fluid-impact media, (the fitted holes), and an arbitrary number f of holes in the MMP are free from the fluid-impact media, (the free holes) to generate the separation between constituent A and constituent B the MMP moves through the capsule captured quantum of fluid with the fitted holes open and the free holes closed.

The separation happens when the two edges are in closed position and the moving MMP moves from E_l, towards the other edge, E_r , forcing the fluid to pass through the open fitted holes, so that at a certain point x between the edges a degree of separation is achieved, then the fitted holes are closed, and the free holes are opened; the MMP then reverses it motion, moving from point x to the E_l until it is located abreast of E_l, at that point the part of the quantum fluid between E_l and point x is richer with constituent A and the part of the quantum fluid between point x and E_r is richer with constituent B. Next the MMP then is switching all its holes into a closed state and moves from E_l towards point X, at the same time the holes in both edges are switched to open so that the movement of the MMP from E_l to point X pushes the B enriched part of the quantum of fluid outside the capsule to a receptacle planned to collect the B enriched part of the quantum of fluid, R_b, at the same time a new quantum of fluid is sucked into the capsule through E_l.

The MMP unit can readily be applied to volatility based separation. Let's desire to separate a fluid Q comprising a more volatile component Q' and a less volatile component Q'' to two parts one richer with Q' and the other richer with Q'', the separation is achieved as follows:

The MMP unit is set to a vertical position, then a quantity of Q in a liquid phase Q_l is pumped though the bottom edge of the MMP unit so that it fills the MMP capsule up to a point x lower than the high end of the MMP unit, and where the MMP is positioned at point x such that the atmosphere is above it, and a quantum of liquid Q_l is below it. Then the bottom edge of the MMP unit cylinder is put in a closed state while the moving MMP is also set to a closed state. Then the moving MMP is rising and thereby generating vacuum below it which is filled with fluid Q in the gaseous phase, where the more volatile component Q' is richer in the gaseous phase while the less volatile component Q'' is richer in the liquid phase. When the MMP reaches the upper edge of the MMP unit, then the fluid below it is partly liquid Q_l and partly in gaseous phase, Q_g. Then the upper edge holes are set to close, the holes of the moving MMP are set to open and the moving MMP is moving down through the gaseous phase of Q, Q_g , until it touches the surface of the liquid phase of Q, Q_l, then the holes of the moving MMP are being put into the closed state. The holes on both edges of the cylinder are set

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to open and the moving MMP is rising towards the upper edge, this movement pumps the liquid phase Q_g to a receptacle outside the MMP unit, while more liquid Q is feeding into the bottom of the MMP unit from a feed source.

The moving MMP is then put again in closed state and the liquid below the piston is pushed down to point *x*, at which point the above distillation sequence is repeated.

Configuration

Any number of well-tailored MMP units may be assembled into a general purpose fluid handling system - a combined fluid operating facility, MMPF, that applies a sequence of chemical engineering unit operations on a set of input raw materials, to generate a desired product, and dispose of parts of the raw materials that did not convert into the desired product.

The figure below (11) compares the standard continuous operational mode with the proposed quantum fluid operational mode.

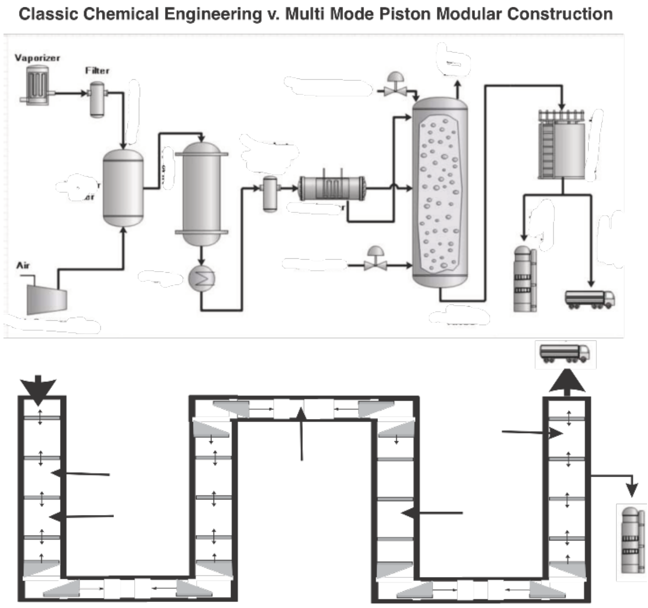

Figure 11. Process Integration.

The MMP units (MMPU) are connected either directly or through capacity tanks. The MMPF is controlled from a central control station that activates and operates the MMPs to coordinate a desired production line for a fluid product. The MMPF is a linear connection of n MMP units, U_1, U_2, ... U_n, such that unit i feeds into unit (i+1) where i=1,2,...n-1, and where

$V_i/(T_i + T_{resti}) = V_j/(T_j + T_{restj})$

where V_k is the volume of the quantum fluid that is contained in unit k, T_k is the time a quantum of fluid is being processed in unit k. and T_{restk} is the time a quantum of fluid is resting in unit k, before or after its processing, where i,j,k = 1,2, ...n, and where $i \neq j$.

The various MMP units may share a geometric direction, (linear setting) or the MMP units are being set at an angle towards each other in which case the shared edge of two non-linear MMP units will be of angular shape to ensure that fluid from a first MMP unit flows to the next in line MMP unit.

The MMPF is set up such that an MMP unit, U_f (the feeding unit) is feeding into t MMP division units where each of the input edges in the division units. U_1, U_2, ... U_t has h_i holes, where i=1,2,...t. We set for the feeding unit to have $f = \Sigma h_i$ holes, summarized over a subset Y of the division units, and where the feeding unit is feeding to the division units in the Y subset, the f holes in the feeding unit are open and the holes in the units of the Y subset are open, while the holes in the units which do not belong to the Y subset are set to a closed state. The feeding unit may feature less than f holes, but rotate so that its feeds is divided between the divisions units of the Y subset.

Similarly, for a different network configuration the MMPF is set up such an MMP unit U_c, the collecting unit, is collecting fluids feeding from t' MMP feeding units where each of the output edges in the division units. U_1, U_2, ... $U_{t'}$ has h'_i holes, where i=1,2,...t' and where the collecting unit has c = Σ h_i holes, summarized over a subset Y' of the feeding units, and where the collecting unit is being fed from the feeding units in the Y' set while the holes in the units which do not belong to the Y' subset are set to a closed state, and the collecting MMP is rotating so that the fluid contents of the collecting MMP is collected from the feeding units of the Y' subset.

Generalizing Hardware, Tailoring Software

The universal structure of the generic chemical engineering building block allows for prime attention to be paid to high quality design of the multi-mode piston unit, spanning sizes, and applications. The market will be filled with many standardized MMPU which every process designer will select from, and then apply the control strategy that represents the process under design. The attention of the industrial chemist and the chemical engineer will be directed to procedural steps while the hardware MMP units will be a standard issue. This is a much better use of the planning time of the process designer.

Micro Drilled Piston

As of now the multi-mode piston (MMP) is the only UUP under a testing state. In preliminary design mode we find the micro-drilled piston. This is a piston comprising micro tunnels that pitch together the content captured in the capsule with carefully pushed in add-on ingredients to an action spot which is controlled per temperature and any other environmental parameters. Micro channel pistons can be manufactured through 3D printing or through more traditional methods involving melted material engulfing washable content. See Figure 12.

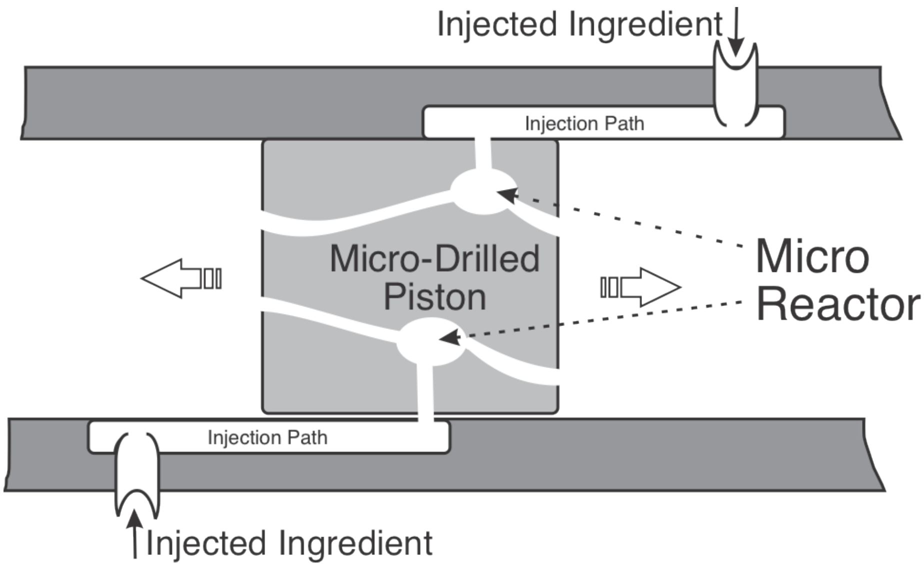

Figure 12. Micro Reactor.

Integrated Motion

The MMP integrates fluid motion power with fluid reactivity and behavior. Classically chemical processes are happening through externally activated pumps that move the fluid through the sequence of steps. The MMP integrates power with behavior. This integration is essential for the AI impact, assuring optimality. The structural similarities between the various functions: mixing, reacting, separating, create a unified database for the AI to chew on. In the future the AI database will serve to recommend the dimensions and the structure of particular MMPs for specific needs.

Equipment Capacity Management

Traditionally a chemical engineer will build the plant to fit the required production capacity. The size of the reactor, the separators, the in-between tanks, the storage tanks, the pumps are all derived from the desired throughput. It is generally very costly to use two twin production lines, with double the number of units, pumps, control wiring etc. This rigidity is alleviated with the UUP. Being of standard structure the UUP are built very economically. They handle their own fluid motion

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power, and their own timing. It makes much more sense to achieve the desired plant throughout through two or more parallel lines. What is more, any particular UUP can be duplicated or triplicated, so that maintenance and enhancement can be applied to the plant while keeping the production hamming. Having *n* parallel production lines will create an *n* multiplier for AI data collection, yielding faster optimization.

Delay Management

Each UUP in the sequence is designed to finish its process with the current quantum of fluid, QoF, over the same time interval T which is claimed by upstream and downstream UUP. This is necessary for a smooth progress of each QoF from the first UUP to the last. Any delay within one UUP will slow down the whole process. To alleviate that delay option one could fit two or more parallel UUP for processes inclined for delay. Such may be in cases of random contamination of feed. Overall faster UUP will be programmed to wait for slower UUP. See Figure 13.

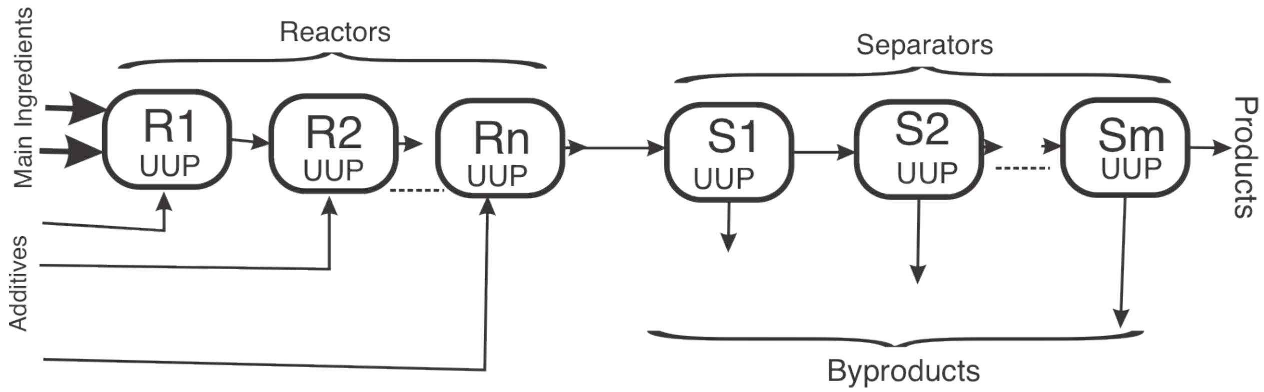

Figure 13. Reactors and Separators.

Content Monitoring

The QoF encapsulating cylinder may be fitted with radiation sensors which examine absorption at given wavelength and return measurements of concentration and chemical makeup to indicate to the control system the extent of readiness of the QoF to be released to the next step.

4. Methodology

The multi-mode piston unit building block for industrial chemistry was developed with the tools of Innovation^{SP} [1]. This innovation science methodology calls for extended run of innovative ideas, in order to define a perimeter of range of impact. Often this range is shrinking considerably as it moves towards implementation. It is expected here too. On paper the MMP building block appears truly universal and it stands to replace the various tanks, vessels and contraptions used in industrial chemistry today. This is very likely an outer unrealistic perimeter. It is more likely that in-pine pumping will be widely implemented, and the same with respect to high-grade mixing, especially when product tolerance is very tight. The application of this building block to separation challenges may be more limited since dedicated separation geometries, especially in chromatography, are well developed.

The Innovation^{SP} methodology calls for very limited restrain on the evolving, "exploding" underlying idea, followed by a more cautious and more level-headed consideration of the subsequent implementation plan. Yet, when it comes to being AI friendly the standardized building block is remarkably promising.

5.AI Strategy

Breaking down the chemical process into a series of quantum units is inherently AI friendly. Each unit can be AI improved, and then AI can optimize the threaded whole.

5.1. UUP-AI

A UUP will have an array of fluid-in Q_i defined through q* attributes, and a fluid-out Q_o array of fluids defined through q properties. It reads s sensors inside the UUP and it control p control points therein. Each controller is divided to r states. The controller associated with this UUP can issue r^p control states at each time interval, t, over a period T_u of operation per a single quantum of fluid. Altogether the degree of freedom per this UUP is tr_p determined from the input data defined by Q_i, Q_o, and s(t) over T_u.

Let the UUP operate 24/7 and let d be the number of quantum sessions carried out by the UUP over a 24 hours period. This amounts to d test cases per day. In each test case the AI logic has an association between the readings of the situations and the control strategy used. It is a rich body of correlation data ripe for pattern-searching supervised AI capability. The optimization of the controllers increases with use. As with similar AI applications this optimization is not based on feeding the algorithms with transport phenomena algorithms, it is a simple evolutionary progress towards the best control strategy.

In the case of the MMP the kinetic control points are (i) the lateral position of the piston, say u positions, (ii) the rotational angles of the piston, a, (iii) the on/off positions of the h holes. This allows for C control states per each time interval:

$C = 2^h * a * u\ (t)$

And many more if the holes can be partially covered.

5.2. Cross UUP AI

While each UUP is AI optimized independent of the others, the n threaded UUP can be AI optimized per the entire process. This will result in changes in the entry state for the various UUP, and revised inter UUP AI optimization.

5.3. Unending AI Optimization

Unlike classic optimization which reads an end point and stays static there, AI optimization is on going. As long as the process is taking place, so does the AI learning and improving going. This allows for dynamic response to changes in raw material, environmental changes, etc.

6.Present Day and Outlook

AI generated models of the proposed quantum fluid operation design, show very positive results. The AI parametric optimization is on solid ground. The concept of UUP is well established. The implementation of UUP with MMP is undergoing experimentation. It certainly works for pumping and reacting. Efficacy for separation tasks is waiting for conclusive evidence.

The foundational intellectual property was formally defined and filed by its developer (the author). In parallel the author is engaging large and innovative industrial chemistry corporations in conceptual discussions of the merit, scope, and expected impact of the quantum approach, as well as in setting up construction projects for various size MMPs to be tested and tried with a variety of fluid options.

In a short time, the author and his collaborators will issue an evaluative and scope report and take it from there. Interested readers are encouraged to respond, react, comment and discuss with the author: Prof. Gideon Samid, PhD, PE. Gideon@DGSgo.com

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