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Innovative Method and Device for the Homogeneous and Delimited Mixing of Fluids and Comparison with Currently Used Systems in the Agri-Food Sector

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ABSTRACT

The Mixer Homogeneous Local in Media (MHLM) system is a device, designed and patented by Stefano Farné and Vito Lavanga, that allows to mix a fluid, increasing its homogeneity and uniformity along surfaces with any profile. The greatest advantage of this device is the possibility of mixing in a localized way and not affecting the entire volume of the fluid. It is a system, not bulky and not expensive because it is made up of elements that can be easily found on the market, consisting of two drainage pipes connected by a circulator and uses the hydraulic technique of "reverse return" in which, thanks to the characteristic arrangement of the pipes, with inlets and outlets placed in a symmetrical and inverse way, it is able to guarantee a symmetrical and uniform distribution of the loads which facilitates the movement of the fluid and improves its efficiency. The mixing process affected by this device is fundamental in many areas of the industry, and is compared, in particular, to the devices currently used in the agri-food industry.

Keywords: Mixer, Fluid mixing,

MHLM

The MHLM invention refers to a method and to a device for the implementation of said method, for the homogeneous and delimited mixing of fluids, both liquid and gaseous, forming part of a fluid mass in motion or in state of rest, and to a device for the implementation of said method. It is strongly felt the need to have systems to mix liquid and/or gaseous phases, in various industrial processes, particularly functional to obtain and/or to accelerate the production processes or services such as, but not limited to, fermentation, chemical reactions, homogenization and maintenance in suspension.

Existing technologies employ various principles of technical physics and chemistry, using articulated installation structures, by resorting to mechanical actions, generally by propellers or blades, in which they are generated vortical motions that, by setting in motion the fluid mass and in interaction the different components, generate the mixing and the suitable homogenization to allow the biological and/or chemical expected processes, but frustrate much of the action imparted by the pushing mechanism with an evident dissipation of the used energy. The devices currently available remedy to this problem by means of complex geometries of "break-vortexes" and/or distributing the motion mechanism in different points of the fluid mass, increasing the plant costs.

In other processes, it is necessary to isolate the mixing space in specific volumes, reducing to a minimum the dispersion in nearby areas. Besides in this case the problem is solved by the use of complicated and expensive systems to stem harmful effects, as vortical and stationary motions. These problems pervade many sectors such as the municipal wastewater treatment plants, the plants for the anaerobic digestion or the microalgae crops. A combination that is not obtainable with the devices currently available is the mixing and simultaneous thrust of a fluid mass with a homogeneous movement and according to a specific plane. This invention constitutes an innovation with respect to the current state of the art, allowing to overcome these problems in a simple and economical way. In summary, in the current state it is not possible to mix a delimited part of a fluid mass, without disturbing the surrounding fluid mass.

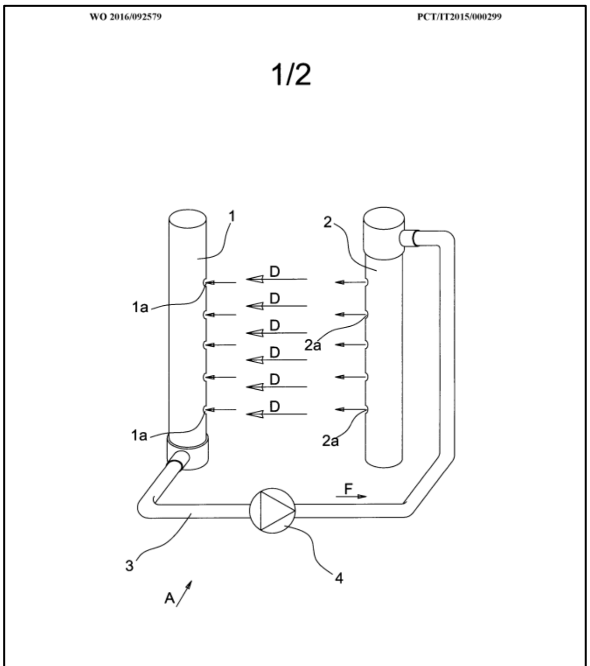

Fig. 1

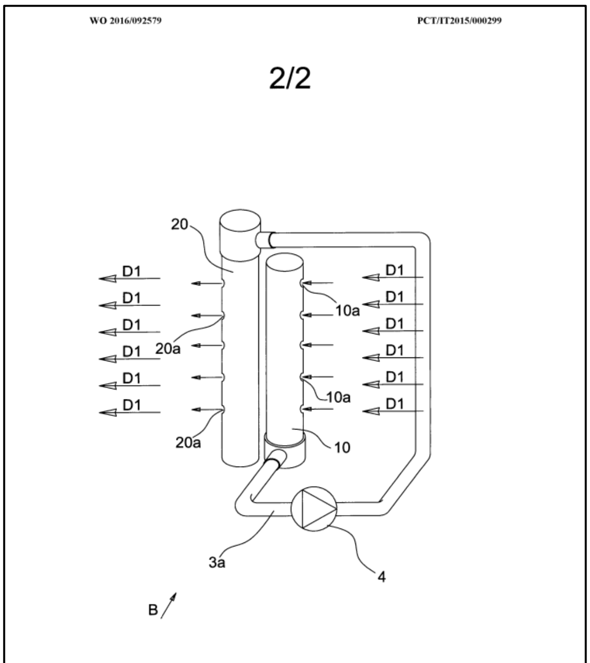

Fig. 2

The method comprises:

- taking part of the material from said fluid mass;
- making a vigorous mixing of the fluid material taken;
- reinserting the fluid mixed material into said fluid mass;

The device (Figures 1 and 2) includes:

- a first manifold (1, 10), closed at both ends, on which a first plurality of holes (la, 10a) is made, aligned along a generatrix of said first manifold (1,10);
- a second manifold (2, 20), closed at both ends, on which it is made a second plurality of holes (2a, 20a) aligned along a generatrix of said second manifold (2, 20);
- a pipe (3, 3a) that connects said first manifold (1, 10) with said second manifold (2, 20);
- pumping means (4), inserted in said pipe (3, 3a), which cause a movement of a fluid contained in said pipe (3, 3a) by said first manifold (1, 10) towards said second manifold (2, 20).

Mixing scales

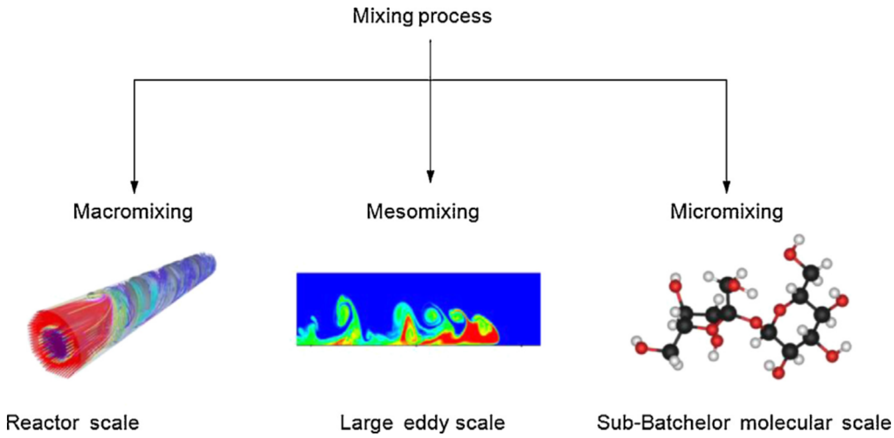

Fig.3. Mixing Scales

Mixing, as a physical phenomenon, is a complex process to study and analyze. For a deeper understanding, it is inevitable to distinguish and describe some simpler mixing stages, namely macromixing, mesomixing and micromixing illustrated in Figure 3 (Ghanem, Lemenand, Della Valle, Peerhossaini, 2014).

- ***Macromixing***

The full-scale mixing in the entire device / tank is called "macromixing". This determines the concentrations in the working environment by connecting the fluid particles in the flow domain. The mixing process is directly dependent on the "average" flow transfer efficiency at different scales. Macromixing represents the dispersive capacity of the flow on the scale of the volume made available by the device and is generally characterized by the residence time distribution (RTD) method as a sign of the uniformity of the velocity field.

In fact, RTD is directly related to the overall movement of the flow since it again represents the time taken by the fluid particles to migrate from the inlet of the device to the outlet.

This large-scale movement, caused by the average flow velocity, drives the fluid particles between the high and low turbulence regions in the mixer volume, resulting in large-scale convective transfer called macromixing. Macromixing can therefore be modified by generating a radial convective transfer, for example creating longitudinal vortices (vortex generators) or by providing deflectors that perturb the path of the fluid by mixing it.

- ***Mesomixing***

Mesomixing represents the intermediate scale, identifiable by the large-scale turbulent exchange between the fluid just introduced and its nearby areas governed by turbulent fluctuations. A rapid chemical reaction is usually localized near the feed point, forming a feed flow crest in the substrate, (figure 3). It identifies an intermediate scale between the micromixing scale and that of the system or tank. The spatial evolution of the feeding crest can be identified with the turbulent diffusion process. Another aspect of mesomixing is related to the inertial-convective process of disintegration of the great vortices. Inertial-convective disintegration mixing of large vortices proceeds without any direct effect of molecular mixing.

However, there is an effect of inertial-convective mixing on the micromix process. The complete understanding and description of mesomix is not a simple task and for this reason many models have been developed that aim to simulate, in the most possible realistic way, the formation and disintegration of the vortices that are present in this mixing scale. They consider various parameters such as turbulent kinetic energy k, the length scale of turbulent fluctuations L and their combination in turbulent diffusivity Dt. They also depend on specific operating conditions such as the diameter of the pipe, the ratio of the flow rate of the feed to the average speed of the flow surrounding the feed point and possible mixing in the feed tube. One of the simplest ways to express the essential characteristics of mixing is to link it to the RMS of the velocity fluctuations.

- ***Micromixing***

Micromixing, the last of the mixing stages, consists in the viscous-convective deformation of fluid elements which accelerates the reduction of the size of the aggregated elements up to the diffusion scale. The selectivity of chemical reactions depends on micromixing: how reactants mix in the molecular scale. This mechanism involves the deformation of the Kolmogorov micro-scale vortices (Batchelor, 1953) and is the limiting process in the reduction of local concentration gradients. It can be characterized by the micromixing time directly related to the dissipation rate of the energy turbulence.

Following the theory of Hinze and Kolmogorov, which is based on the idea of the energy cascade, the breaking of the dispersed phase bubble of a multiphase flow is also characterized by the dissipation rate of turbulent kinetic energy. Therefore, an increase in this dissipation rate favors the micromixing process, improving the selectivity of fast chemical reactions and also reducing the maximum size of bubbles dispersed in multiphase flows.

Classification of mixers

First of all, the mixers are differentiated according to the type of drive of the organ that carries out the mixing. More specifically, we talk about:

- static mixer, that is, an equipment used to mix two fluid streams (generally liquids) together without the aid of moving components. The energy required for static mixing is provided by the movement of the fluids themselves, driven by gravity, pumps or blowers. A static mixing unit can in fact be formed by a series of mixing elements inserted in a duct, according to the direction of the flow. They have various shapes: generally they form variously "intertwined" or helical structures (Fig. 4). The two fluid currents conveyed in the pipe, encountering these fixed elements, undergo sudden changes in direction and come to meet each other, mixing (Paul, Atiemo-Obeng and Kresta, 2004). In addition, static mixers can also be assimilated to those composed of pipes in which the fluid flowing, again with the aid of pumps, mixes thanks to the diffusive properties of the fluid;

- dynamic mixer, on the other hand, is a device that has a moving part inside (turbine or impeller with vanes) which, through the turbulence created in the fluid by their movement, mix the substances. It is possible to recognize equipment such as propeller or rotating vane agitators and turbine agitators, with or without blowing air. These devices are generally used for discontinuous processes or, in the case of water treatment, in open basins; rarely in pressure pipes, where a static mixer is more suitable. Dynamic mixers provide good energy dissipation near the blades or diffusers, but as you move away from them, the efficiency drops significantly.
- In the case of highly miscible fluids in turbulent regime (this is the case of many gases), a T-junction is sufficient to carry out the mixing.

Static mixers

A static mixer can be a hollow pipe or channel with a specific geometric construction that influences the flow structure to promote secondary cross flows that improve mass and heat transfer in the cross section. Another type of static mixer concept is the insert configuration, whose typical structure is a series of fixed inserts of various sizes and geometries that can be installed in pipes, channels or ducts. The purpose of these elements is to redistribute the fluid in the directions transverse to the main flow, i.e. the radial and tangential directions. The static mixers divide and distribute the flow lines using only the pumping energy of the fluid flowing inside. The inserts (fig. 5) can be customized and optimized for particular applications and flow rates.

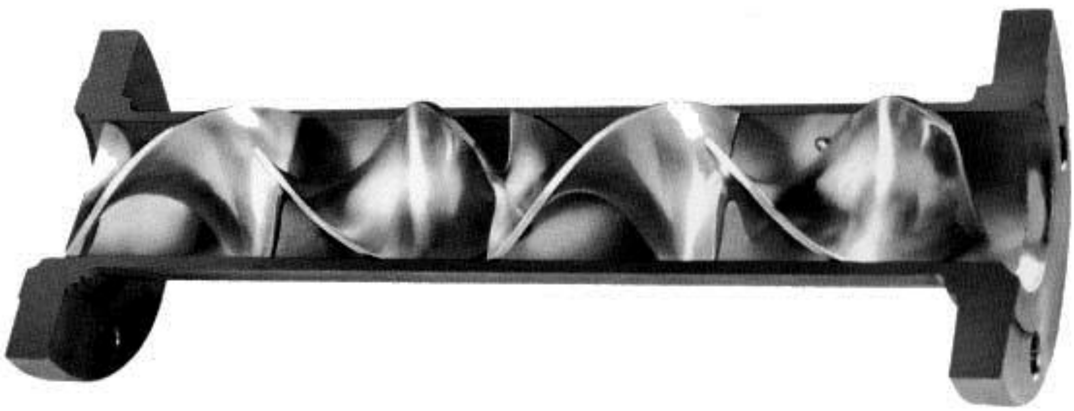

Fig.4. Example of static mixer

A static mixer can be a hollow pipe or channel with a specific geometric construction that influences the flow structure to promote secondary cross flows that improve mass and heat transfer in the cross section. Another type of static mixer concept is the insert configuration, whose typical structure is a series of fixed inserts of various sizes and geometries that can be installed in pipes, channels or ducts. The purpose of these elements is to redistribute the

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Fig.5. Examples of inserts for static mixers

The most common use of static mixers in industry is in mixing miscible fluids. Two or more fluids or a reagent mixture are mixed to reduce or even eliminate concentration gradients, for example to incorporate the enzymes needed in milk to make the yogurt. Static mixers can also be used for mixing solids, where they are gravity fed, and for mixing particulate solids such as cereal grains, bread and cake mixes and components. Dispersion of gases / liquids such as ozonation of drinking water is a common application in modern industry. The applications of static mixers in the food industry are numerous. Food products are usually highly viscous, typically non-Newtonian fluid, and are usually processed in the laminar regime. The literature shows that static mixers are used to mix juices, oils, beverages, chocolate, milk drinks or sauces and many others.

Their surfaces are generally electropolished and are mostly made of AISI 316 stainless steel and housed in sanitary tubes of similar materials. Water clarification treatment and sludge treatment can also make use of these devices. Turbidity in drinking water is caused by suspended solid particles at low concentrations. Static mixers are used to disperse a flocculating agent, such as alginate, as the first clarification step.

In this case the flows are in the turbulent regime, but an excessive shear force, that could be caused by mechanical agitation, can damage the flocculated elements, leading to a high consumption of the flocculating agent and thus losing its efficiency. Static mixers are also good tools for mixing gases and pre-vaporized liquid fuels before a reaction. Indeed, this is the first recorded use of a static mixer (Sutherland, 1874). Despite the diffusivity of the gases, the mixtures do not immediately reach homogeneity and further mixing may be necessary for a good combustion. Baker (1991) discussed their use in nitric acid production.

Static mixers placed upstream of a reactor to mix air with ammonia increase nitric acid yield and eliminate hot spots that can damage the expensive platinum catalyst. Many chemical reactions involving gases can be improved by using static mixers, such as those for the production of vinyl chloride, ethylene dichloride, styrene, xylene and maleic anhydride (Baker, 1991).

Dynamic mixers

In literature there are many types and models of dynamic mixers used in the most diverse operations and in the most varied fields. The types that provide a system of blades to carry out the mixing are the most common and include a tank containing the fluid to be mixed, in which the equipment is inserted to carry out the mixing. The tank is equipped with a sealing system, through various gaskets, for operation with the tank closed.

The components used for mixing are generally formed by a propeller, or in any case a system of blades of various shapes, types and materials based on the characteristics of the liquid to be mixed, such as its viscosity or its corrosive capacity, therefore by a shaft that transfers the torque at the propeller, connected in turn to the motor which supplies the energy necessary for the process. Usually the shaft turns at a speed lower than or equal to that of the motor for which a reduction system is often provided consisting of toothed wheels or belts.

The shaft on which the blades are mounted and the blading itself are the most expensive components to size and on which most of the mixer efficiency is based. Often the tanks contain elements called deflectors that affect the efficiency of the device because they insert an increase in the turbulence of the fluid.

The materials of construction, although usually metal alloys, depend on the chemical processes and operational requirements. Paddle mixers differ according to the mounting position with respect to the tank and the power put into play by the motor which makes some mixers more suitable for some processes than others.

Top-entering mixers

These, as the name suggests, are mixers that are mounted on top of a tank (Fig. 6). They can be of various sizes, the smallest are considered portable or laboratory mixers, not suitable for industrial operations. They provide for mounting flanged or pedestal supports, and clamps or turntable supports for smaller models. In addition, they can be mounted both centered with respect to the vertical axis of the tank, which has deflectors along the internal surface, but also off-center or mounted at an angle.

The shaft can be operated and connected directly to the motor or there may be a reduction system to match the speed of the motor to that of the shaft. The motors used in these mixers do not exceed 7460 W (10 HP) of power. Most top-entering mixers have an axial flow impeller, such as a hydrofoil impeller or sometimes a marine propeller (Paul, Atiemo-Obeng & Kresta, 2004).

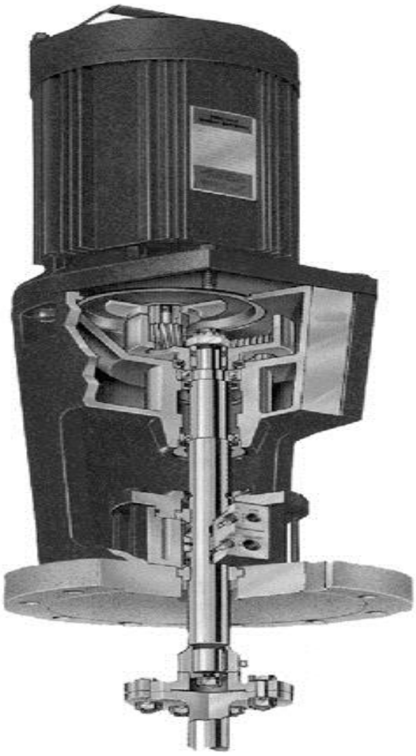

Fig.6. Top-entering mixer

Turbine mixers

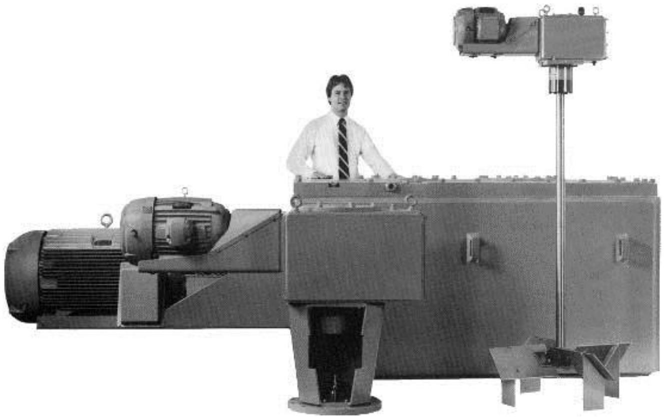

Fig.7. Turbine mixer

Turbine mixers are vertical mixers that require a more robust design, especially with regard to the shaft and blading, and use motors that provide power ranging between 746 W and 746,000 W (range in which they can fall also the top-entering). Given the wide range of usable powers, they can also have very different dimensions, as shown in the image in Fig. 7. They are usually mounted vertically in cylindrical tanks or basins or rectangular boxes and are also equipped with gasket sealing systems in the case of closed tank operations. The design of the shaft and the blading system is fundamental and critical in mixers of this type especially for the various possible powers to be put into play which makes this mixer versatile for different types of fluid and for different applications (Paul, Atiemo-Obeng and Kresta, 2004).

Side-entering mixers

The Side-entering mixers, Fig. 8, are mounted on the side of the tank providing the possibility of being mounted below the liquid level, usually at the bottom level to mix even low levels of compounds. This is also the major drawback of these mixers. In fact, they have submerged sealing gaskets which, according to the nature of the working fluid, can be compromised by chemical actions or by the possible abrasive nature of the fluid which subjects the gasket to deterioration due to wear. For this reason, they usually require rather expensive maintenance.

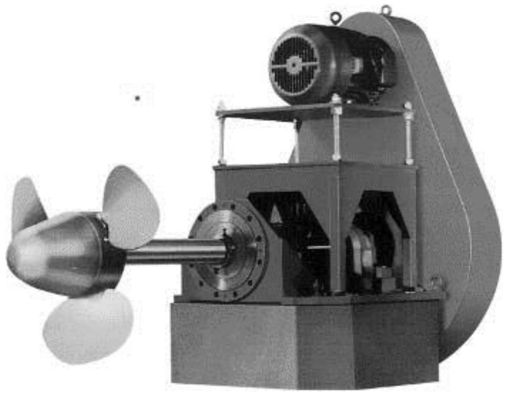

Fig.8. Side-entering mixer

On the other hand, side-entering mixers have advantages over the aforementioned types, especially from an economic point of view, allowing low initial costs, the absence of mounting supports on top of the tank and the use of simple reduction mechanisms. The high speed of the blades of this type of mixers which usually allows to use the direct connection with the shaft (Paul, Atiemo-Obeng and Kresta, 2004).

Bottom entering mixers

Bottom-entering (Fig. 9) are mixers with the same constructive characteristics of the turbine mixers, but they foresee the mounting on the bottom of the tank. It therefore has the same disadvantages as the side-entering mixers, for example as regards the aggressiveness of the fluid on the seals, without however providing the advantages that the latter are able to guarantee on the economic side. Given their low efficiency compared to other different types of mixers, their use is limited to applications where other types of assembly are impractical due to the particular shape or geometry of the tank (Paul, Atiemo-Obeng and Kresta, 2004).

Fig.9. Bottom entering mixer

High viscosity mixers

These types of mixers are designed to mix fluids with high viscosity values, 100 000 cP or higher, through the use of blades that reduce the space between the blades and the internal walls of the tank, or completely eliminate it thanks to the use of flexible flanges. This feature leads the size of the impellers to be much larger than that usually used for turbine mixers.

Fig.10a. Helical belt impeller for viscous fluids

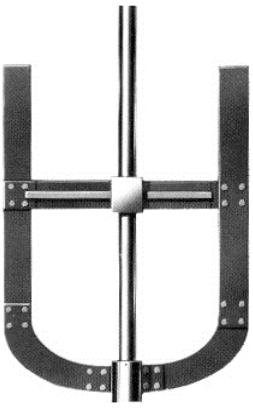

Fig.10b. Anchor impeller for viscous fluids

The most important characteristics of high viscosity mixers are the low rotation speed and the high torque given to the shaft, to overcome the strong viscous resistances due to the fluid. Furthermore, their efficiency is influenced by the shape of the blades which must be designed case by case based on the diameter of the tank and the viscosity of the fluid. Two examples of impeller can be helical belt, Fig. 10a, or anchor impellers, Fig. 10b (Paul, Atiemo-Obeng and Kresta, 2004).

High-shear mixers

The mixers of this type have opposite characteristics to those belonging to the mixers for high viscosity, having a diameter of the impeller much smaller than that of the tank, even 10-20% compared to the diameter of the container, and operates with high speeds of revolutions, from 1000 to 3600 rpm. The smaller size of the impeller, compared to the mixers exposed previously, has the purpose of reducing the power required by the motor to support high speeds.

The impellers can appear as discs with teeth protruding along its edges, Fig. 11a, or cylindrical in shape with holes or slots on the rotating part, forming a typical impeller called rotor-stator impeller, Fig. 11b. As the rotating blades pass through each opening in the stator, they mechanically cut particles and droplets, decreasing their size and thereby increasing the stability of the phases in the mixture, and expel the material at high speed into the surrounding mixture. The faster the material is ejected, the more it is drawn into the impeller which promotes continuous flow and rapid mixing. While being able to provide vertical mounting in the tank, many high-shear mixers are used in line, as if they were pumps with blades capable of imparting a high shear stress, through which the fluid flows or is pumped. They therefore work mainly as static mixers, with a flow set in motion by an external pump (Paul, Atiemo-Obeng & Kresta, 2004).

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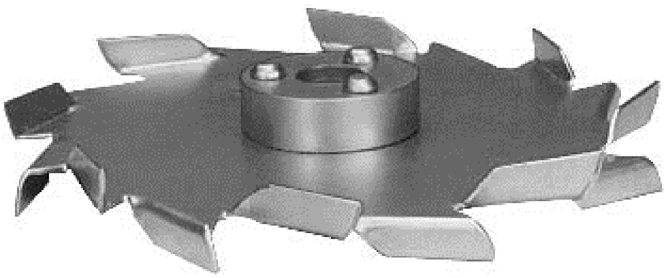

Fig.11a. High-shear disc impeller. The teeth protruding from the edges are visible

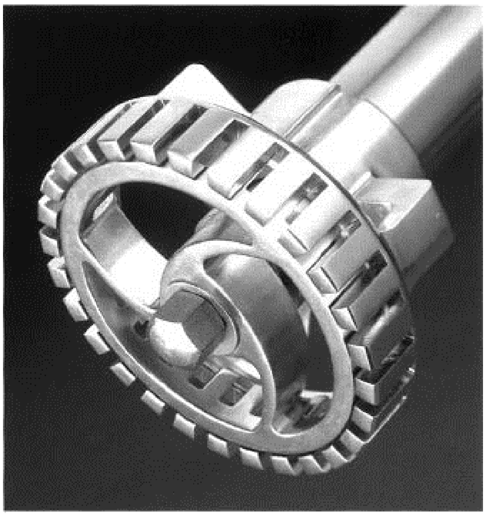

Fig.11b. Rotor-stator impeller for High-shear mixer

Combined mixers: Dual-Shaft or Triple Shaft Mixers

that combine the characteristics of the different mixers mentioned above through the use of two distinct shafts and at least two impellers: the part for mixing high viscosity fluids of the mixer provides the movement of the fluid mass inside the tank, in particular near the walls, and the High-shear mixer creates the dispersion, often of two phases, two liquids or one liquid and solid. The High-shear part can also include both disc impeller and rotor / stator solutions, forming a three-shaft mixer increasing the value of the supported viscosity (Fig. 12). They are mainly used in the agri-food sector for the processing of syrups, sauces, peanut butter and others.

Fig.12. Triple Shaft Mixers: one shaft with rotor-stator impeller (left), one with anchor vanes (center) and one shaft with High-shear impeller. Each shaft is operated and moved independently of the others

Some of these devices instead have two coaxial shafts with two types of impellers, one for viscous fluids and the high shear action, which rotate at different speeds, or with one of the two distinct shafts which, in addition to turning around its axis, rotates around the axis of the tank, as in planetary mixers. Their costs, although higher than specific mixers for mixed fluids, are compensated by their versatility of use in various industrial applications.

MHLM

The MHLM mixer described in this paper mixes fluid volumes using a circulation pump. It can be assimilated to a static mixer, leaving the pump out of the definition being able to be of various kinds and having the purpose of circulating the fluid through the mixer, as well as increasing its mixing action. It represents a great innovation in the field of industrial mixing because thanks to the components used, i.e. drainage pipes easily found on the market, and to their arrangement to ensure the reverse return, it is able to mix along pre-established surfaces, with a flat, circular, sinusoidal profile, segmented, etc., and in localized portions of the fluid without involving and affecting the total existing volume. The devices available on the market have not this possibility and, to mix only portions of fluid, maybe present in a certain area of a tank to keep substances of different densities in suspension or to facilitate chemical reactions, use blades which, although designed to mix in a limited way, will inevitably also involve a part of the adjacent volume, significantly lowering the efficiency of the mixer and of the desired process. Furthermore, by arranging the outlet and inlet drainage tubes so that it sucks in fluid on one side and returns it mixed on the other, MHLM can create a uniformly mixed fluid flow, thus combining the mixing capacity with that of actuation and movement of the fluid along specific directions.

Functioning and Mathematical Model of MHLM

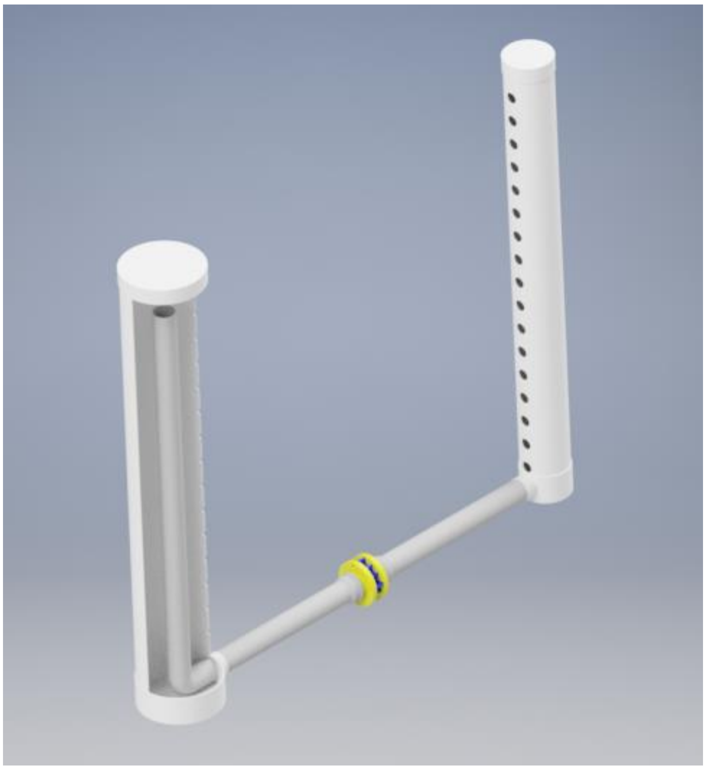

Fig.13. Render of MHLM mixer

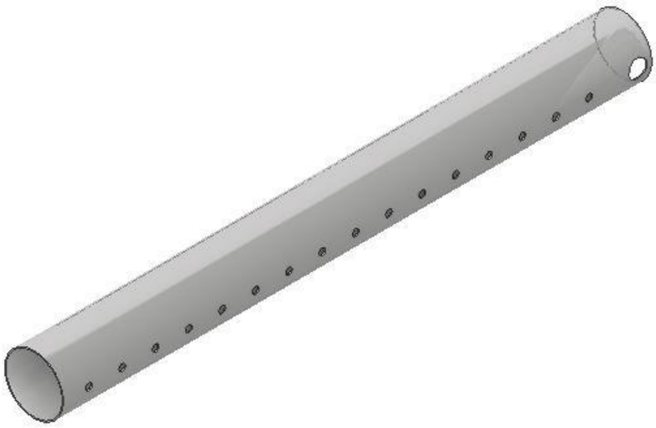

Fig.14. Drainage Pipes used in the mixer

Once the pump set up for mixing and circulating the fluid is activated, it will enter the device through a first manifold, consisting of a plastic tube or material suitable for the substances to be mixed, closed at one end and with small holes along the length. The flow will be distributed evenly along the pipe, thanks to the reverse return arrangement in which the two manifolds are arranged. Also these pipes to ensure that the flow is continuous and without preferential ways, in addition to the reverse return, must respect the following relationship,

$A_{D\ int} \leq \sum A_{holes}$

The flow, once sucked by this first manifold, thanks to the depression created by the circulation pump, will start a first mixing action inside it and then pass into the circulator. It must have dimensions suitable for the mixture to be processed, therefore have such diameters as not to risk clogging the pipes once in operation and be composed of materials resistant to any chemical aggressiveness of the substances (PVC, metal, Teflon, and the like). In the passage through the circulator, the fundamental part of the mixing will take place thanks to the passage of the fluid through the impeller of the pump. Here the size of the dispersed phase particles will decrease thanks to the action of the pump impeller and will be distributed evenly in the flow due to the turbulence created. In the following branch without holes, the mixing will be strengthened, thanks to the delivery pressure created by the pump and to phenomena of radial diffusivity, and subsequently the fluid will be distributed homogeneously along the second perforated manifold to exit the device and re-enter the reaction volume.

Losses and Power

For the device to work effectively, the pump must overcome the friction and losses that are created during the flow of the mixture in the manifolds and in the circulator. Along the way the fluid will be subject to continuous losses which can be calculated by,

$$\Delta p = \frac{\rho\, \lambda\, v^2 L}{2d} \quad [\text{Pa}]$$

λ : coefficient of friction with the walls

L, d: length and diameter of the tube and ρ : fluid density.

In turbulent conditions the coefficient of friction λ depends on the Reynolds number (Re). To calculate it, the Coolebrooke White formula can be used:

$$\frac{1}{\sqrt{\lambda}} = -2\log(\frac{2,51}{Re\sqrt{\lambda}} + \frac{\varepsilon/d}{3,7})$$

Where: ε/d= relative roughness

It is analytically complicated, so in practice you can use the Moody's abacus or simplified formulas obtained from experimental tests, which vary according to the roughness of the wall in which the fluid flows.

For low roughness pipes:

$$\lambda = 0,316\ Re^{-0,25}$$

For medium roughness pipes:

$$\lambda = 0,07\ Re^{-0,13}\ D^{-0,14}$$

To carry out a more precise calculation, accidental losses must also be taken into account, which in the device under examination can occur with changes in the direction of the pipes, by the formula:

$$\Delta p = \rho\ \xi\ \frac{v^2}{2} \quad \text{[Pa]}$$

with: $\xi =$ tableless dimensionless coefficient that takes into account the type of accidental loss.

In this way it is possible to calculate the head that the pump will have to overcome

The prevalence formula in the design phase is:

$$H = H_g + \frac{p_b - p_a}{\gamma} + \frac{\Delta p_{tot}}{\gamma} \quad \text{[m]}$$

with:

γ: specific weight

H_g: geodesic height

p_b, p_a: delivery and suction tank pressure respectively

Δp_{tot}: total pressure drops, sum of continuous and accidental leaks

Since the delivery tank is the same as the suction one, it arises H_g=0 and $p_b = p_a$ (therefore $p_b - p_a$=0), and therefore the prevalence is equal only to the sum of the losses along the entire device.

$$H = \frac{\Delta p_{tot}}{\gamma} \text{ [m]}$$

At this point it is therefore possible to calculate the useful power that the pump will have to supply:

$$N_u = \frac{\gamma Q H}{102} \quad [\text{kW}]$$

Energy and mixing efficiency

The energy yields of MHLM are to be attributed to the system and essentially to the chosen pump. As regards the efficiency of the mixing process, a CFD fluid dynamics simulation would be very useful in order to estimate this parameter. They are believed to be of good importance considering the motion of the flows and the possibility of carrying out this process in a localized way.

Representation of MHLM loads

The path that a "fluid thread" travels through inside the device can be summarized as follows.

- *Manifold in depression (intake)*

The pressure p_0 which will suck the fluid, applied to the outlet of the first collector, will suffer from continuous losses so it will not be constant along the axis of the pipe. Considering the manifold placed in the fluid, the holes at the bottom will already have an entering pressure given the hydrostatic pressure, gradually decreasing upwards, so it is advisable to position the suction pipe in the upper part of the pipe, to apply maximum suction. In addition, the depression will gradually be less from the lower holes to the upper ones, more precisely:

$$p_n = p_0 + \Delta p_{perdite}$$

with p_n: nth hole pressure

The pressures will therefore increase along the length of the pipe and as the suction depth of the hole increases.

- *Circulation pipe*

The circulation tube is a simple non-perforated tube that has 90° bends. Given the suction pressure upstream of the pump, it will be modified in the course of the pipe due to pressure drops, distributed and concentrated. It can be represented with the Bernoulli equation

$$p_{asp} + \rho g h \; = p_0 + \Delta p_{perdite} + \rho g h$$

Subsequently, the fluid will enter the pump where it will undergo the pressure drops of the pump and then come out with a delivery pressure. Knowing the latter, you can always calculate with Bernoulli how this pressure decreases along the second circulation pipe to reach the outlet manifold. Then

$$p_{man} + \rho g h \; = p_u + \Delta p_{perdite} + \rho g h$$

- *Manifold under pressure*

The fluid will then enter the delivery manifold with a previously calculated pressure. It must be sufficient so that even the last hole is under pressure. The vertical perforated pipe will have the inlet at the bottom (as opposed to that of the intake manifold, to have reverse return). Each hole will therefore be subject to the pressure supplied by the pump purified from leaks and hydrostatic pressure (in this case contrary to that of the fluid leaking)

$$p_m = p_u - \Delta p_{perdite}$$

Considering the area with the two facing manifolds, in order to create a laminar flow the difference in pressures, between facing points pair by pair along the axis of the pipes, must be equal so that there is a uniform distribution, along the height, of the pressures.

Therefore p_m-p_n =cost

$$p_m - p_n = (p_u - p_0) - \frac{\rho\,\lambda\,v^2}{2d}(L + L')$$

For example, considering the pair 4-4 the previous formula becomes

$$p_4 - p_4 = (p_u - p_0) - \frac{\rho\,\lambda\,v^2}{2d}(L_4 + L'_4)$$

As $(L_4 + L'_4) = L$ (with L = length of the perforated tube) and then

$$p_m\text{-}p_n = (p_u - p_0) - L\left(\frac{\rho\,\lambda\,v^2}{2d}\right)$$

with the term on the right of the equal constant.

The procedure therefore demonstrates the homogeneity of the loads which causes a laminar flow to be created between the two collectors.

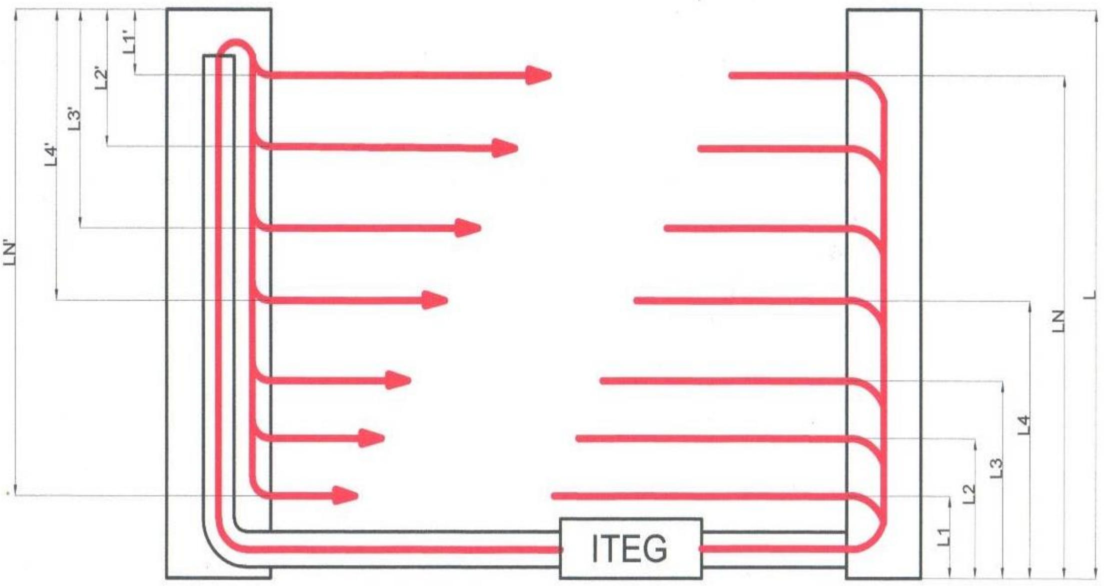

Fig.15. Graphic representation of the flows of the MHLM mixer

Conclusions

MHLM is a very versatile device and its use can be advantageous in many industrial fields such as the food industry, for example in the production of yogurt, to homogenize the product and the reactions inside it, or in the production of beer to standardize the fermentation of hops. It can be used in both small and large plants and requires minimal maintenance. It is achievable with a low construction cost, given the materials that can be easily purchased on the market, but also a low cost of use. MHLM, above all, presents the great advantage of being able to mix only a portion of a given volume, and it can be usefully used for example:

• to support a gentle excitation to avoid sedimentation phenomena (e.g. microalgae cultivation);

• in wastewater conditioners where it is necessary to set in motion a delimited zone and to leave stationary the others;

• to support the delimited mixing level to hydrolytic portion in the anaerobic digestion, that will be the subject of a next scientific paper.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional and personal interests.

Ethical Approval

Based on institutional guidelines.

Consent to participate

The consent to participate in this research was sought for and approved by the subjects to be used.

Consent for publication

Authors declare that they consented for the publication of this research work.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

Patent

LAVANGA, Vito - FARNE', Stefano Method and device for the homogeneous and delimited mixing of fluids – MHLM (https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2016092579)

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