

# The Gravity Separation Mixture Fluid: Detailed Description of the Device and Possible Applications

Farné Stefano

Department of Industrial, Electrical, Computer and Biomedical Engineering, University of Pavia, Italy.

DOI: <http://doi.org/10.46382/MJBAS.2022.6104>



**Copyright:** © 2022 Farné Stefano. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Article Received: 16 November 2021

Article Accepted: 21 February 2022

Article Published: 18 March 2022

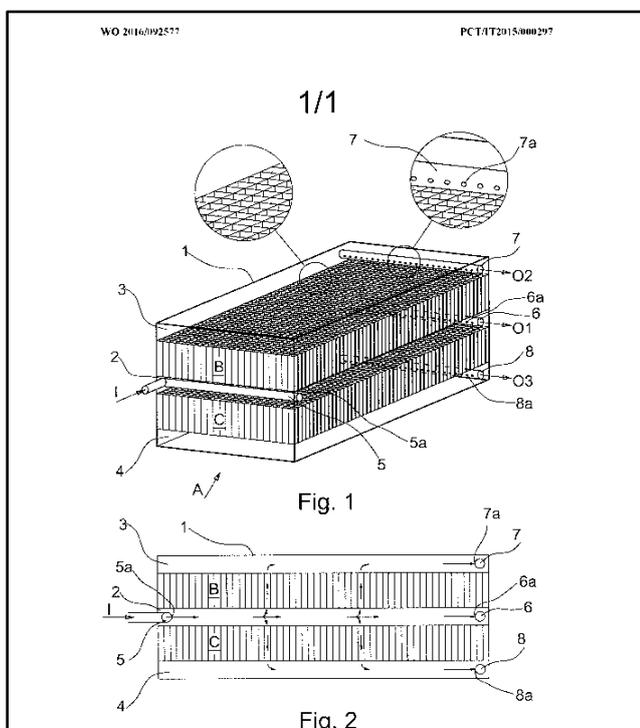
## ABSTRACT

The system Gravity Separation Mixture Fluid (GSMF) is a device designed and patented by Stefano Farné and Vito Lavanga, described in the scientific paper "The Gravity Separation Mixture Fluid: An Innovative Method and Device to Separate the Components in a Gas, Liquid or Vapour Mixture". GSMF allows to separate a mixture into its various components with different specific weights, exploiting the stationing of the fluid in the spaces created by each of two packs of honeycomb which, in addition to increasing the surface useful for the separation of the mixture, provides the vertical space useful for eliminate the horizontal motions that would make the gravimetric separation process vain. The flow necessary for the passage inside the device is guaranteed by inlet and outlet draining pipes from which to extract the different phases of the mixture, arranged in an arrangement for three-dimensional reverse return.

## Method and Device Description

The method is of the type which provides for the execution of the following steps:

(1) creation of a horizontal flow of a fluid mixture, wherein the fractions are arranged on different levels as a function of their density; (2) taking those fractions through taking means positioned on each of said levels; the



separation of those fractions being obtained by the only effect of gravity and of the hydrostatic thrust which derives therefrom and it is characterized by the use of means fitted to delimit the areas in which the flow is exclusively vertical and not disturbed by the horizontal flow, in such a way as to promote the desired separation, because not disturbed by turbulence and transverse motions. These vertical movements generate additional horizontal movements formed by fluids of different density.

The device is of the type which includes:

- means fitted to create a horizontal flow of the fluid mixtures, in such a way that the fractions are arranged on different levels as a function of their density;

- taking means positioned on each of those levels, fitted to individually take the fractions;

wherein the separation of the fractions is obtained by the only effect of gravity and of the hydrostatic thrust which derives therefrom and it is characterized in that it comprises a first and a second block, each one of which

comprises a plurality of vertical channels, fitted to delimit the zones in which the flow is exclusively vertical and not disturbed by the horizontal flow. These blocks are inserted in a container, so as to locate:

- a first gap, between the blocks;
- a second gap, positioned above the first block;
- a third gap located below the second block;

being provided:

- input means, positioned in correspondence with a first end of the first gap;
- taking means, positioned in correspondence with a second end of the first, second and third gaps.

When all volume comprised in container is filled with a mixture of fluids of different density, these fluids being:

- run into the container through the input means;
- taken from the container through the taking means, that are differentiated in function of the different density of the fluid.

The device is now described with reference to the figures, wherein:

- Fig.1 shows the device;

- Fig.2 shows the diagram of the operation of the device.

With reference to fig. 1, with (A) it is indicated a device (gravimetric separator) that comprises a first (B) and a second (C) block, each of which comprises a plurality of vertical channels. The blocks (B) and (C) are inserted in a container (1), indicated by the lines of greater thickness and are positioned inside the container (1) so as to locate the following three gaps:

- a first gap (2), between the blocks (B) and (C);
- a second gap (3), positioned above the first block (B);
- a third gap (4), placed below the second block (C).

At the two ends of the first gap (2) are positioned a first inlet pipe (5) and a first outlet pipe (6). According to a preferred embodiment, the first pipe (5) and the second pipe (6) are cylindrical and, on each of them, a plurality of holes are made, respectively (5a) and (6a) aligned along a generatrix of the cylinders. In the second gap (3) and in the third gap (4), in correspondence with the first outlet pipe (6), are positioned respectively a second outlet pipe (7) and a third outlet pipe (8). Also in this case, on each one of said outlet pipes (7) and (8) a plurality of holes is made, respectively (7a) and (8a) aligned along a generatrix of the cylinders. The flow of the mixture that must be treated, indicated by the arrow (I) enters into the first pipe (5), from which it exits through the holes (5a) and it invades the whole volume enclosed by the container (1). Under the thrust of the entering flow, the mixture exits from the three outlet pipes (6), (7) and (8), passing through the holes (6a), (7a) and (8a) respectively.

The mixture that must be treated flows through the first gap (2), moving toward the first outlet pipe (6). By establishing a laminar flow regime, the fraction of the mixture having a lower density will be inclined to rise towards the first block (B), entering in the vertical channels, where it will find the state of rest to leave the gravity act, and here it will run into the second gap (3). At the same time, the fraction of the mixture having higher density will be inclined to descend towards the second block (C), entering in the vertical channels, where it will find the state of rest to leave the gravity act, and here it will run into the third gap (4). Finally, the fraction of the mixture having an average density will remain in the first gap (2).

As a consequence, it will be possible to gather three fractions of the mixture from the three outlet pipes (6), (7) and (8), the flows of said three fractions being represented by arrows (01), (02) and (03), respectively for the fraction of medium density, of low density and high density.

By observing the arrow (I), which indicates the flow entering the device (A), and the arrows (01), (02) and (03), which indicate the outgoing flows, it is possible to note that the conditions of reverse return are made. The movement in the inlet pipe (5) and in the outlet pipes (6, 7, 8) extends in a direction perpendicular to the direction of the streams in the gaps (2, 3, 4), while the movement in the vertical channels of the blocks (B, C) is simultaneously perpendicular both to the flow in the gaps (2, 3, 4), and to the flow in the pipes of the inlet (5) and outlet (6, 7, 8). In this way it is realized the reverse return in three-dimensional option. In practice the mixture to be separated is run into a side of the laminar flow that develops in the gaps and taken in correspondence of the opposite side of said laminar flow. For example, by inserting in the separator (A) a mixture comprising protein and oleic fractions, the various fractions will have the following behavior:

- the oleic fraction having a lower density, will gather at the top in the second gap (3), and therefore it will be taken from the second outlet pipe (7);
- the protein fraction, having higher density, will gather at the bottom in the third gap (4), and therefore it will be drawn from the third outlet pipe (8);
- the remaining fraction, consisting mostly of water, will remain in the first gap (2), and can be taken from the first outlet pipe (6).

According to a preferred embodiment (not shown), in the container (1) a number of blocks (B, C, etc.) greater than two are positioned, in such a way as to identify a number of gaps greater than three; this arrangement allows to make splits, greater than three fractions, of the components present in a mixture, obviously of different density among them.

### **Device sizing**

With reference to Fig. 3, the two main dimensions of the device (L and B) are assumed, which must be congruent with the space in which the device will be installed. From data coming from sector documents it is possible to find the standard separation times of some mixtures subjected to phase separation tests or to carry out preliminary tests, using for example the Imhoff cones which can give an estimate of the sedimentation time of the mixture in question. Taking these times as those to be guaranteed of permanence inside the device, the total height H of the

honeycombs can be dimensioned (given by the sum of the two partial heights  $h_1$  and  $h_2$ ) such as to guarantee these times. More precisely, we will act on the relationship between the total volume of the honeycomb packs and the flow rate processed by the separator to ensure that the set times are guaranteed. By indicating with  $V$  the total volume made available by the honeycombs and with  $Q$  the incoming flow arises:

$$t_{sep} \leq \frac{V}{Q} = \frac{L*B*H}{Q}$$

with  $t_{sep}$  : established separation time

$V$  : available volume of overall honeycomb

$Q$  : fluid flow

$L$  : length of the honeycomb package

$B$  : width of the honeycomb package

$H$ : overall height of the honeycomb

At this point, through the inverse formula, it is possible to calculate the minimum total height to guarantee the stay in the honeycombs for the time initially established ( $t_{sep}$ ):

$$H_{min} = \frac{t_{sep} * Q}{L * B}$$



**Fig.3.** Main dimensions of the two honeycomb packs

This height will then be divided between the upper and lower honeycomb pack in proportion to the percentages of portion with higher and lower specific gravity, respectively, in the mixture. The interstices must also have heights proportional to the concentration in the initial fluid of the phase it will host. Furthermore, they can also be oversized to facilitate separation and act as reservoirs in which to accumulate the specific phase.

By applying concentration sensors in the upper and lower interstitium, the respective valve could be activated for the extraction of the phase until the sensor measures an incorrect concentration of the desired phase in the extracted phase. All piloted and controlled by PLC. Another important factor to consider is the size and shape of the shaft section. These parameters can be chosen on the basis of the physical characteristics of the mixture. Working mixes can be:

- ✓ Liquids with macroscopic bodies in suspension (mm): in this case the section of the shafts must be such as to prevent clogging during the flow of these bodies. A preliminary analysis of the fluid will therefore be required.
- ✓ Liquids without suspended bodies, therefore consisting of liquid phases with a significant difference in specific weight: in this case the area of the section has less influence on the feasibility of the process, except in the case in which the section of the shaft is too small (becoming subject to phenomena of capillarity), which would lead to a predominance of the adhesion forces between the molecules of the fluid compared to those of cohesion between the fluid and the shaft wall, preventing the fluid from entering the shaft.
- ✓ Gaseous with bodies in suspension (for example with bodies of the order of ppm, such as particulate matter): the shafts must have a suitable section to ensure that the bodies in suspension, by settling and encrusting the walls of the shafts, do not create the clogging of the latter.
- ✓ Gaseous without suspended bodies (mixtures of "pure" gases such as CH<sub>4</sub>, CO<sub>2</sub>, CO, N<sub>2</sub>, NO<sub>x</sub>, ...): the shafts must have an appropriate section only for the phase separation times at rest and as a function of the respective specific weights.

When fully operational, the path that the "fluid thread" will travel through consists of the path in the inlet pipe, that of the laminar flow in the interstitium to reach the shafts, in the vertical shaft (lower and upper), the laminar one to reach the outlet and the one in the outlet tube. By estimating the load losses in the device it is possible to demonstrate the operation of the reverse return. The following cases are possible:

- Perforated tube (inlet)

Absolute pressure  $p_0$  which will allow the fluid to enter the pipe, applied to the inlet hole, will suffer from continuous losses due to the passage in the inlet pipe, so it will not be constant along the axis of the pipe. The holes near the inlet will have a pressure very similar to that of the inlet which will decrease more and more moving away from it. More precisely:

$$p_n = p_0 - \Delta p_{losses} \quad \text{with } p_n: n^{\text{th}} \text{ hole pressure}$$

- Depending on the distance from the inlet hole, the losses will increase moving away from it and therefore the pressures will decrease along the axis of the pipe.
- Laminar flow in the central gap

The flow exiting the holes on the manifold will form a horizontal laminar flow. This is due to the reverse return along the horizontal plane, guaranteed by the inverse and symmetrical loads of the inlet and outlet pipes. It too will suffer losses due to the advancement along the interstice. The head losses will be uniform along the orthogonal plane of the device, at the same distance from the starting point, and will increase instead as you proceed from the inlet to the outlet pipe for the increasingly longer section that each "fluid thread" will have to travel.

- Vertical shaft

Once the flow enters the shaft it will slow down considerably, due to the absence of horizontal motions. Here the gravimetric separation will take place, and the loads will be constant along the orthogonal plane of the device, for each battery of shafts as for the flow in the interstitium, and those of the inlet and outlet pipes will reverberate in and out of the shaft, dampened by the path to be made in the interstices.

- Laminar flow in the upper and lower interstitium

Once the separation has taken place, therefore after the time spent in the shaft, the flow will be attracted into the interstice, upper or lower, by the depression created in the manifold in the perforated outlet pipe, appropriately calibrated. The outlet pipes can be provided with valves controlled by PLC which, through concentration meters of the phase concerned, will open or close the valves, in this way you can also choose whether to take the component from the central gap.

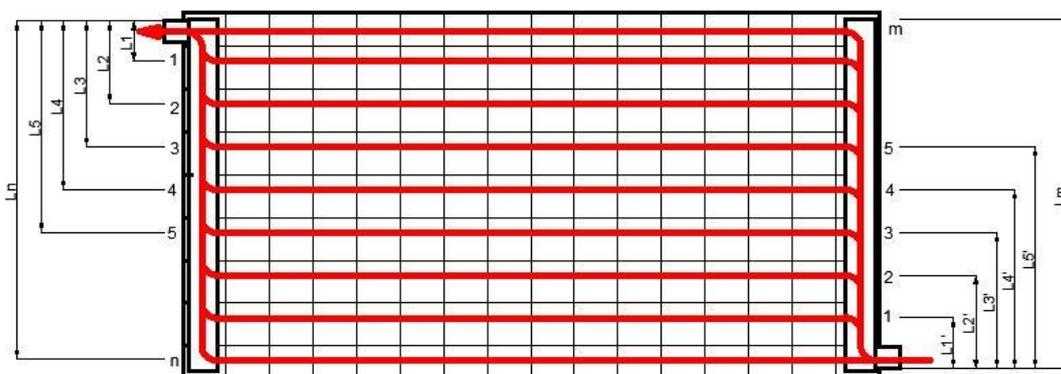
- Perforated tube (outlet)

The actual pressure  $p_u$  which will allow the fluid to exit the device through the outlet pipe, applied to the outlet hole positioned on the opposite side with respect to the inlet, it will also be affected by continuous losses so it will not be constant along the axis of the pipe. More precisely, being a vacuum tube

$$p_m = p_u + \Delta p_{losses}$$

With  $p_m$ : pressure hole  $m_{th}$

Depending on the distance from the outlet hole, the losses will increase moving away from it and therefore the depressions will decrease along the axis of the pipe. The reverse return that governs the operation of this device can be considered a “double reverse return” for each honeycomb pack as this hydraulic technique is verified both on the horizontal and on the orthogonal plane. As for the horizontal plane, the reverse return will be essential to create a laminar flow in the central gap, and to create constant loads at the entrance and exit of all the shafts at an equal distance from the starting pipe.



**Fig.4.** Representation of the loads along the horizontal plane of the interstices

Considering facing holes, the pressure difference between them must remain constant for all pairs of holes distributed along the length of the pipe. Therefore,

$$p_m - p_n = \text{const}$$

By making the difference, and considering the losses as the distributed losses incurring in the section of perforated pipe, it is obtained:

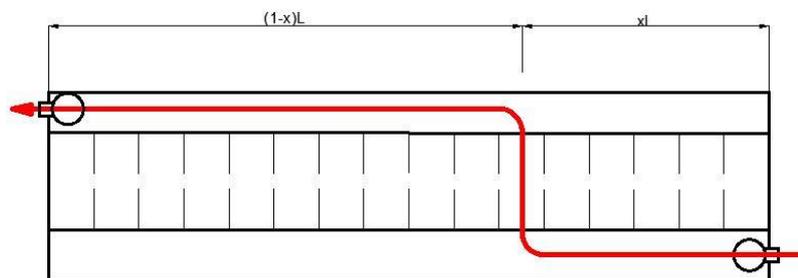
$$p_m - p_n = (p_u - p_0) - \frac{\rho \lambda v^2}{2d} (L_n + L'_m)$$

For example for the pair 5-3 (Fig. 4) the formula becomes,

$$p_5 - p_3 = (p_u - p_0) - \frac{\rho \lambda v^2}{2d} (L'_5 + L_3)$$

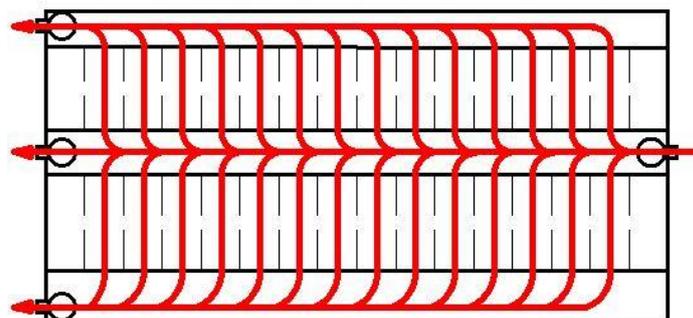
As  $L'_5 + L_3 = L_{tubo}$  and the length of the pipe is constant, so the term to the right of the equal is constant for each pair of holes and the reverse return along the horizontal plane is therefore verified.

As for the reverse return along the orthogonal plane, considering an orthogonal plane  $xL$  away from the departure, in the first section where the fluid runs through the central gap there will be losses proportional to the distance from the inlet pipe ( $xL$ ). Subsequently the "fluid fillet" will enter the shaft where it will be stationed for the separation to take place. Finally, it will have to cover the interstice section (lower or upper) and then exit the device. Therefore, considering a load  $p_0$  at the beginning of the path, it will be damped by a quantity proportional to  $xL$  and subsequently to  $(1-x)L$ , the sum of which indicates that each fluid thread will be subjected to overall head losses proportional to  $L$ , with  $L$  = length of device, whatever the distance of orthogonal plane from the inlet pipe.



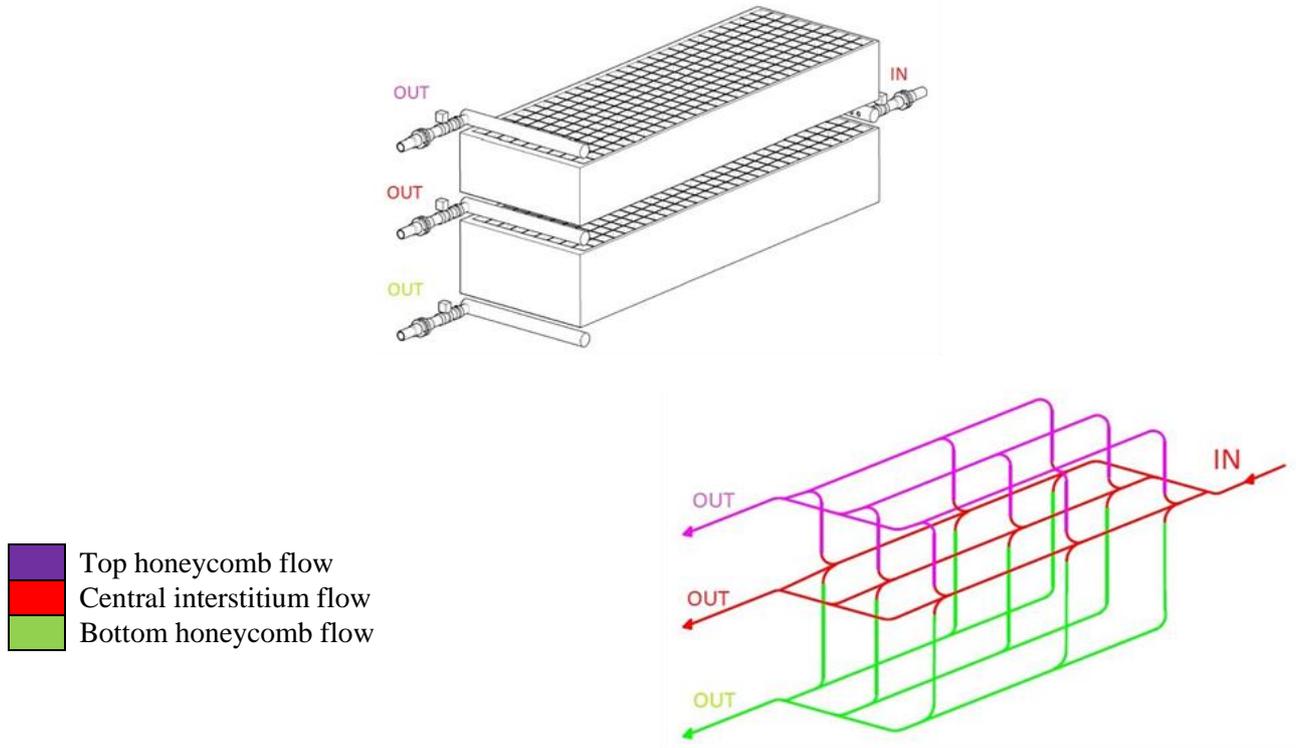
**Fig.5.** Representation of the flow along the vertical orthogonal plane at a distance  $xL$  from the entrance to the upper honeycomb

The same reasoning can be carried out for each distance  $xL$  from the entrance, therefore for each row of shafts and for both honeycombs, obviously symmetrically with respect to the laminar plane of the central interstice.



**Fig.6.** Representation of the flows on the vertical orthogonal plane for each transverse row of shafts

Both inverse returns, the one along the horizontal plane and the one along the transverse vertical planes, must be understood as coexisting and cooperating dynamically so that we can speak of a three-dimensional inverse return and the device can function correctly.

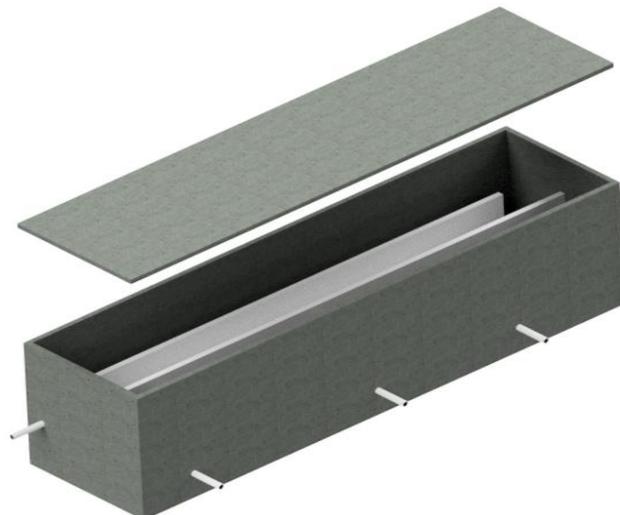


**Fig.7.** 3D graphic representation of the interaction of flows inside the GSMF separator

### Applications and Comparisons with Similar Devices

#### *Application of GSMF to a MBGC mini biogas plant*

The use of biomass, as both domestic and agricultural wet waste, for the production of biogas is increasingly widespread.



**Fig.8.** Render of the mini-biogas MBGC

This process can be implemented through anaerobic digestion of biomass, which is a biochemical type process in the total absence of oxygen. The process takes place through the demolition of organic substances by means of microorganisms that produce a gas (biogas) consisting of 50-70% of methane and the remainder of carbon dioxide. Biogas can be used for the production of electricity in cogenerators, where the engine exhaust heat is conveniently used to keep the digester temperature at an ideal level.

The MBGC (Mini BioGas Continuous) is an integrated system designed and patented by Stefano Farnè and Vito Lavanga, described in the article "Innovative Small Size Plant for the Production of Biogas and Electric Energy from Biomass". It can be integrated with small agro-food and urban housing settlements. The peculiarity of this plant is that it will exploit the organic results of these structures through special hydraulic systems that have the function of withdrawing and introducing the waste material into the plant. The main objective of MBGC plant is to recover as much energy as possible from the organic waste material and to reuse the by-product of anaerobic digestion in such a way as to maximize yield. The tributary, consisting of biomass coming from urban waste or effluents or from companies in the agri-food sector or which in any case produce organic wet waste, follows a path inside a suitably sized tank divided into compartments in which the organic material is subjected to chemical reactions, different along the way, generating clear haloclines characterizing specific biochemical phases, which leads to the production of the aforementioned products. The insulated container is a watertight parallelepiped. The MBGC is divided into three macro-volumes by means of two partitions with a height equal to  $\frac{2}{3}$  of the total height. The first two volumes are placed in communication through a "natural" passage provided by the vertical opening left by the length of the first septum while to connect the second and third volumes a more ingenious system is used to filter the compound that has now finished the digestion and, at least as regards the energy contribution given by biogas, it has nothing more to offer. The third volume is divided into three sub-volumes that cover it in width and are kept at an appropriate distance, useful to ensure that different types of salts can be deposited in three different stages. The salts will then be collected by pumps positioned at the corners where presumably the latter will settle.

In various points of the structure, in the recycling phase at the end of the second volume and for the entire duration of the third volume, gravimetric separation of the fluid is used. At the end of the second volume, it is operated to divide the oleic and protein part from the ideal one for the continuation of the cycle: in this way it is possible to recycle them. At the end of this section, once the anaerobic digestion is over, the fluid will ideally have three distinct phases: one more protein at the bottom, one more oleic in the upper part and the ideal one to continue the cycle, almost exclusively composed of "ash" (i.e., the salts and microparticles, both suspended in solution, no longer having consistency characteristics to gravitate significantly) and water, in the center.

Furthermore, a modified configuration of GSMF but exploiting the same principle is useful to implement and facilitate the separation of the biogas produced, separating carbon dioxide, heavier, and methane, lighter, so that they can be reused by satisfying the required concentrations from the purposes they will aim at. In the third volume, by means of two dividing septa, the gravimetric separation is used to have a division from the fluid into three different types of NPKx salts. The operation of MBGC is very influenced by the use of gravimetric

separation. In fact, it is exploited both in the second volume in which the separation of the oleic, protein and salts part takes place, strongly encouraged in the last part of this volume in which the oleic and protein part are extracted, having not yet been digested during the process. , or by now so microscopic as not to undergo predominant gravimetric effects, compared to the part with medium density, salts and ash, which instead will continue the path in the digester to get to the last volume; but also in the third volume, in which thanks to this process, salts of different density and composition can divide from the water and deposit in the three different micro-volumes created, based on their physico-chemical characteristics. This occurs both for solutions with dissolved salts of different specific weight and for microparticles, which will form, with dynamic sedimentations, chemoclines of the foreseen compartments. A gravimetric separation is also carried out for the separation of the biogas produced, into carbon dioxide and methane. The GSMF separator finds an ideal use in the last part of the second volume in which, without the use of GSMF, the designer had to create a surface that would improve the already natural propensity of the mixture to separate, still obtaining an inefficient separation. It could be placed in the last 3 meters of the second volume in which, given the width of the section of 0.8 m, there is a maximum surface available for the separator of,

$$A = 3 * 0,8 = 2.4 [m^2]$$

The volume to be treated will enter the device thanks to the hydrostatic thrust produced by the introduction of new wastewater, including that coming from the internal recirculation, into the tank. Therefore the volume that the device will have to make available is at least 2,000 liters so that all the handled volume can be subjected to further gravimetric separation in GSMF. So you can find the height to be guaranteed by the lamellar packs, then to be divided into upper and lower honeycomb based on the percentage quantities of the phases present in the fluid.

$$H_{min} = \frac{V}{A} = \frac{2}{2.4} = 0,85 [m]$$

Which is rounded to 0.9 m. Considering all the available height up to the top of the dividing partition of the first and second volume of 1.67 m, a height of,

$$1,67 - 0,9 = 0,77 [m]$$

Considering an equal quantity for the two phases, oleic and protein, in the composition of the wastewater at this stage of transformations, the height dedicated to the honeycombs will be divided into two for the lower and upper one and the remaining height will be divided between the interstices, preparing for the central interstice as often as possible in order to facilitate the separation processes in vertical shafts. The separation time will certainly be guaranteed thanks to the long stationing of the fluid in this last area of the second volume.

In fact, new material to be separated will enter the reactor on a daily basis, guaranteeing approximately 24 hours of certainly sufficient time for separation. Another important use of gravimetric separation is identifiable in the treatment of the gas phase. The digestate in the first and second volume is subjected to chemical reactions whose product is biogas, as previously stated, composed of CO<sub>2</sub> (carbon dioxide) and CH<sub>4</sub> (methane), both gases widely used in various industrial fields, which therefore must be separated and collected individually.

The specific weight of methane ( $0.66 \text{ Kg} / \text{m}^3$ ) is lower than that of air ( $1.18453 \text{ Kg} / \text{m}^3$ ) and lower than that of  $\text{CO}_2$  ( $1.68 \text{ Kg} / \text{m}^3$ ), and the large difference between the specific weight values for due gas suggests the use of a gravimetric separator, considerably reducing the costs for the extraction of the two gases which would not otherwise occur inside the digester but with techniques in separate processes. For this purpose, a separator attributable to GSMF with some structural and functional differences is positioned on the partitions present in the tank, occupying the entire surface formed by the first two volumes. It is made up of two honeycomb packs, as well as GSMF presented so far. The first is made of metal, possibly assisted by an adherent coil / evaporator of the heat pump, in order to condense the humidity inevitably produced by anaerobic digestion, creating droplets that fall back into the substrate, thus carrying out a dehumidifying action, and it is positioned and supported directly by the two dividing walls the tank with two different spacers, on the first and second part, so as to favor the sudden passage of  $\text{CO}_2$  towards the relevant sampling point. It will take care of eliminating the horizontal actions allowing the mixture to separate, containing and recovering the densest phase of the biogas or the  $\text{CO}_2$ . The second, on the other hand, is positioned above the first, leaving an interstice between the two necessary for the handling and extraction of  $\text{CO}_2$ , and is made of plastic material; it will take care of isolating the mixture from horizontal motions so that the lightest phase, ie  $\text{CH}_4$ , can be recovered and extracted. The substantial difference with GSMF presented previously is that the structure just illustrated provides for the introduction of the fluid from below through the entire surface of the honeycomb, and not through the drainage tube inlet of the central interstitium, therefore absent in this configuration. Considering a width of 1.2 m, given by the sum of the width of the first volume (0.4 m) and the second (0.8 m) and a length of the tank of 10 m, we obtain a useful surface of,

$$A = 1,2 * 10 = 120 \text{ [m}^2\text{]}$$

and having available from the top of the dividers, located at 1.67 meters, to the upper wall of the tank a height of,

$$H_{max} = 2,5 - 1,67 = 0,83 \text{ [m]}$$

the latter will be divided consistently with the different quantities of methane and carbon dioxide produced.

Leaving  $\cong 7 \text{ cm}$  for the interstices, there are 0.60 m remaining for the honeycomb packs. The website [www.arpae.it](http://www.arpae.it) (of the regional agency for prevention and environment of Emilia Romagna) reports a quantity of methane in the biogas, with an average calorific value of  $23 \text{ MJ} / \text{Nm}^3$  coming from anaerobic digesters, of 65-70%, the remainder is to be attributed to carbon dioxide and other gases in smaller quantities depending on the type of biomass digested.

The heights of the honeycomb packs could respect this proportion, resulting

$$\text{Upper honeycomb} \rightarrow h_s = 60 * 0,65 \cong 40 \text{ cm}$$

$$\text{Lower honeycomb} \rightarrow h_i = 60 * 0,35 \cong 20 \text{ cm}$$

### **$\text{CO}_2$ capture from anthropogenic settlements and combustion processes**

The scientific community believes that an excessive concentration of greenhouse gases in the atmosphere is among the main causes of global warming. Worldwide, it is estimated that 40% of carbon dioxide emissions are

anthropogenic and attributable to the combustion of fossil fuels. One of the possible actions for the mitigation and stabilization of greenhouse gas concentrations in the atmosphere is the Carbon dioxide Capture and Storage (CCS), that is a set of technologies and processes that consist in the separation of CO<sub>2</sub> from point emission sources of the type industrial, transport to a collection point and long-term isolation from the atmosphere for their marketing and further use.

Currently CO<sub>2</sub> is typically removed to purify other industrial gases, but in most cases it is released into the atmosphere without a flue gas treatment. Capture processes are also used to obtain significant quantities of CO<sub>2</sub> for commercial use, starting from exhaust gases generated by the combustion of coal or natural gas. Its importance is also known to be used to produce fertilizers and to gas water. CCS should be better applied to large emission sources, such as power plants and industrial processes due to the high costs that are difficult to sustain by smaller companies.

There are three main approaches for capturing carbon dioxide from the combustion process of a primary fossil fuel (coal, natural gas or oil), from biomass or a mixture of both.

- The first consists of plants with post-combustion capture, or systems that separate carbon dioxide from the gases produced by the combustion of primary fuel in the air. They use a liquid solvent to capture the small fraction of CO<sub>2</sub> (3-5% of the volume) present in an exhaust gas, of which the major constituent is nitrogen. For a combined cycle power plant or plant, the post-combustion system uses an organic solvent, typically monoethanolamine (MEA). Post-combustion CO<sub>2</sub> capture is mainly applied to coal-fired power plants, but can also be applied to gas-fired turbines. In a typical coal-fired power plant, fuel burns with air in a boiler to produce steam, which sets in motion a turbine that generates electricity. The fumes that come out of the boiler (exhaust gas) are mainly made up of nitrogen, CO<sub>2</sub>, O<sub>2</sub>, water vapor and traces of impurities. The separation between CO<sub>2</sub> and this gaseous flow is difficult because the anhydride is present in low concentration and at low pressure. In addition, the impurities, particulate matter, (sulfur dioxide and nitrogen oxide) in the exhaust gas can degrade the absorbent substances and reduce the effectiveness of some CO<sub>2</sub> capture processes. Because the CO<sub>2</sub> partial pressure in the exhaust gas exiting a fossil fuel power plant is low, technologies conducted at high CO<sub>2</sub> partial pressures, such as physical solvents or membranes, are not applicable for post-combustion capture. At the partial pressures typical of a coal-fired power plant, only chemical solvents exhibit adequate absorption capacity.

- Pre-combustion capture plants, on the other hand, are systems that process the primary fuel in a reactor with steam and air or oxygen to produce a synthesis gas consisting mainly of carbon monoxide and hydrogen. The pre-combustion technology is based on the conversion of fuel into Syngas. Syngas is a mixture of CO and H<sub>2</sub>, and is produced by a partial oxidation of coal in a gasifier. To increase the amount of hydrogen, an exchange reactor is used, which converts water and carbon monoxide (H<sub>2</sub>O and CO) into hydrogen and carbon dioxide (H<sub>2</sub> and CO<sub>2</sub>). Before the fuel reaches the burner, the CO<sub>2</sub> is separated from the hydrogen and, the latter, is subsequently burned to produce the heat necessary to generate steam, constituting a carbon-free energy resource. Although the initial conversion steps are more elaborate and expensive, the high concentration of CO<sub>2</sub> produced by the second reactor and the high pressure make it easier to separate. Currently, technologies that operate in post and pre-combustion

for power plants can capture 85 to 95% of carbon dioxide produced. Higher capture yields would also be possible, but this would imply an increase in size, cost and energy expenditure for the separation step.

- Oxycombustion.

These are pre-combustion systems that use oxygen instead of air for the combustion of primary fuels, to produce a burnt gas consisting mainly of water vapor and a high concentration of CO<sub>2</sub>. The water vapor is then removed by cooling and compressing the gaseous stream. Oxycombustion requires the separation of oxygen from the air, upstream of the process, to have 95-99% pure O<sub>2</sub>. The burnt gas may then require subsequent treatments, such as the removal of pollutants and nitrogen, before the CO<sub>2</sub> is stored. This system is still in the demonstration phase.

### **Syngas**

Gasification is a chemical process that allows the conversion of carbon-rich material, such as coal, oil or biomass, into carbon monoxide, hydrogen and other gaseous substances (constituting the Syngas). The thermal degradation process occurs at high temperatures (above 700-800 °C), in the presence of a sub-stoichiometric percentage of an oxidizing agent, typically air (oxygen) or steam. The resulting gaseous mixture constitutes what is called synthesis gas and itself represents a fuel. Gasification is a method of obtaining energy from different types of organic materials and also finds application in the thermal treatment of waste and is used using a system called gasifier. The use of the gasification process for heat production has some advantages over direct combustion, at the cost, however, of the introduction of some system complications. Syngas can be burned directly in internal combustion engines, or used to produce methanol or hydrogen, or converted into synthetic fuel. To date, however, there are very few plants that produce synthetic gasification fuels and the existing ones mainly use coal as raw material. Gasification, in fact, can also use raw materials otherwise not very useful such as fuels, such as organic waste.

Furthermore, the gasification process allows removing with the ashes otherwise problematic elements for the subsequent combustion phase, such as chlorine and potassium, allowing the consequent production of a very clean gas. The combustion of fossil fuels is currently widely used on an industrial scale to produce electricity. However, considering that almost any type of organic material can be used as a raw material for gasification, such as wood, biomass, or even plastics, this can be a useful technology in increasing the contribution of energy. Technologies for the capture and sequestration of carbon dioxide emissions could be applied to the biomass gasification process, as to other combustion processes. Given the usefulness of Syngas to reduce CO<sub>2</sub> emissions during combustion for the creation of electricity, and also due to its versatility of materials from which it is created, the inclusion of the GSMF gravimetric separator could be envisaged.

It would facilitate the separation of the different phases constituting the syngas so as to obtain the greatest efficiency from this fuel, being able to serve the various purposes by guaranteeing the recycling and use of the burnt gases. Considering a potential composition of the syngas produced during a pyrolytic decomposition process (table below), three batches differentiated by different molecular weights are highlighted

- Carbon dioxide (CO<sub>2</sub>) - Hydrogen and methane and other inert gases (H<sub>2</sub> and CH<sub>4</sub>) - Carbon monoxide and nitrogen (CO and N<sub>2</sub>)

This difference in their molecular weights suggests the potential use of the GSMF gravimetric separator. Its design can begin by considering an available volume of 50 m<sup>3</sup> (volume of a container 2500x2500x8000 mm) and designing the dimensions of the honeycombs and interstices according to the composition of the Syngas. Considering the arrangement with the honeycombs adjacent to the internal surface of the separator inlet, the surface available for the honeycombs can be calculated, obtaining

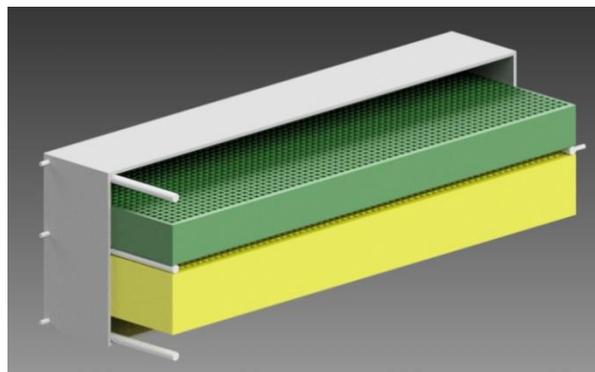
$$A = 2,5 * 8 = 20 \text{ [m}^3\text{]}$$

The three lots considered occupy a certain percentage of the initial mixture to be treated

- Carbon dioxide (CO<sub>2</sub>) -> 16% - Carbon monoxide and nitrogen (CO and N<sub>2</sub>) -> 72% - Hydrogen and methane (H<sub>2</sub> and CH<sub>4</sub>) and other inert gases -> 12%

By dividing the height in two, half for the honeycomb section and half for that of the interstices so that they can act as reservoirs where the concentration of substances can be increased, you get 1.25 m for both portions. It was decided to consider 1.5 m for the honeycomb section, so as to oversize them in order to benefit more from their action on horizontal motions, and 1 m for the honeycomb section. The honeycomb section will consist of two lamellar packs 0.6 m high, the one at the top and 0.9 m the one at the bottom (in order to take into account the percentage difference between the "light" and "heavy" phases). It is therefore possible to calculate the minimum retention time for gravimetric separation to occur considering a design flow rate of 100 l / min (0.1 m<sup>3</sup> / min)

$$t_{sep} = \frac{L * B * H_{min}}{Q} = \frac{8 * 2,5 * 1,25}{0,1} = 250 \text{ [min]}$$



**Fig.9.** Render GSMF for Syngas

### Capture of CO<sub>2</sub> from the air

The capture of CO<sub>2</sub>, as well as in the combustion processes in thermoelectric plants or urban settlements described in the previous paragraph, can take place to remove excess CO<sub>2</sub> free in the air. It may involve natural methods, for example by planting large forests, or artificial methods that use properties of carbon dioxide to be extracted. There are already plants in the world for this purpose and the first to conceive and build one was the Swiss company Climeworks, based in Zurich, which in 2017 inaugurated the first plant for capturing CO<sub>2</sub> directly from the air. The project uses filters specially designed and reusable thousands of times, composed of porous granules modified with amines (substances with the presence of nitrogen), which ensure that carbon dioxide binds to the humidity of the

air by separating from it. Once saturated, the filter will be heated to a temperature of 100 °C in order to release carbon dioxide to be stored and used for other purposes, such as the production of fertilizer, to make carbonated drinks or to be conveyed in greenhouses to heat them. The various separator filters are arranged to create large batteries forming a large air collection surface. This first plant is located on the roof of a waste incineration plant outside Zurich, so that the heat needed to separate the CO<sub>2</sub> from the filter is obtained directly from the residual heat of the plant. Also in Italy there is a plant of the company, as well as in Switzerland and Iceland, inaugurated in 2018 in Troia, in the province of Foggia, which aims to capture 150 tons of CO<sub>2</sub> per year. The problem with these technologies is that they have to extract a highly diluted substance in the air (being present in percentages of 0.03-0.04%) with the need for huge plants to treat a sufficient quantity of air to extract tons of CO<sub>2</sub>. In fact, the project aims to extract one percent of the quantity annually emitted into the atmosphere, equal to some tens of billions of tons, by 2024. This implies an enormous amount of carbon dioxide to be extracted which, considering the costs, declared by a Climeworks co-founder, Christoph Gebald, of about \$ 400 per ton. of CO<sub>2</sub> captured, makes clear the need for huge amounts of money to finance the project and the large number of similar plants, about 250,000, to be built around the world to support the intended purposes.

In this context, the use of the GSMF separator can be found to be very effective. In fact, it would allow to carry out an air separation allowing to reduce costs, not having to create particular filters and not requiring heating for the extraction of CO<sub>2</sub> from them. Furthermore, it would also allow to capture from the air as well as carbon dioxide, even oxygen, which can be used in other processes or to increase the percentage of oxygen in areas where it may be lacking, and from nitrogen, an inert gas that can be admitted back into the atmosphere or usable for other necessary purposes.

**Table 1.** Air Composition

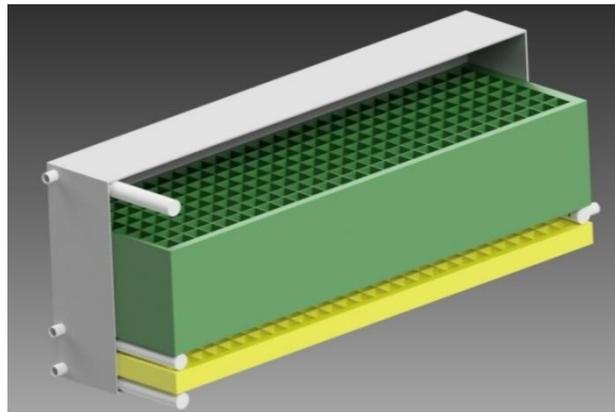
<b>Components of Air</b>	<b>Molecular Weight [u]</b>	<b>Composition [%]</b>
<b>Carbon Dioxide (CO<sub>2</sub>)</b>	44	0.03
<b>Oxygen (O<sub>2</sub>)</b>	32	21
<b>Nitrogen (N<sub>2</sub>)</b>	28	78
<b>Other gases</b>	-	0.97

By analyzing the molecular weights of the substances making up the air (Table 1), it is possible to identify the three batches characterized by a different specific weight in which it is desired to divide the air with GSMF (three-phase).

Assuming the dimensions of 1500x450x600 mm for the device and assuming a reference time, possibly to be modified and evaluated on the basis of experimental tests with Imhoff cones or previous experiences for the gravimetric separation of air, of 30 min and a flow rate of 7 l / min (0.007 m<sup>3</sup> / min) there is a minimum height to be guaranteed by the honeycomb packs of,

$$H_{min} = \frac{t_{sep} * Q}{L * B} = \frac{30 * 0,007}{1.5 * 0.45} = 0.31 \text{ m} = 31 \text{ cm}$$

It must be divided taking into account the substantial difference in composition between the heavier carbon dioxide and the lighter nitrogen. We chose 5 cm for the lower honeycomb, oversizing it to allow more surface area to be available for the separation between carbon dioxide and the other heavier phases, and 30 cm (4 cm more than the minimum ones to guarantee separation times to oversize and ensure better separation given the space available) for the upper one. The remaining height will be divided between the interstices, reducing the central interstice to a minimum and preparing a good part of it for storage of the predominant nitrogen quantity in the mixture.



**Fig.10.** Render of the GSMF device for capturing CO<sub>2</sub> from the air

### **Acidification of the oceans to capture CO<sub>2</sub> from the air**

There are also other ways to capture carbon dioxide from the air. About 30% of CO<sub>2</sub> emissions in the air are captured and absorbed by the oceans, for example, but this process can be increased. The "Desarc-Maresanus" project, developed by the Politecnico di Milano, has studied a process of alkalization of the seas to counteract two environmental problems of great importance at the same time: the increase in concentrations of carbon dioxide (CO<sub>2</sub>) in the atmosphere and the consequent acidification of the oceans. The process consists in the spreading of calcium hydroxide on the surface of the sea which, combining in a spontaneous process with water and CO<sub>2</sub> removed from the atmosphere, increases the buffering capacity of marine waters towards acidity and allows to counteract the decrease in pH. It would require a great economic effort, as there are not yet existing ships with this technology, and an enormous quantity of fresh water to mix with the hydrated lime Ca (OH)<sub>2</sub>. Two scenarios were produced considering 100 million tons per year and as much as 200 million per year. According to these studies, the Mediterranean Sea could absorb 145 million tons per year more than it does now. Obviously, this technology should be integrated with others to support such high numbers of substances used and the number of areas in the world in which to implement these processes. It will also have to deal with developments in the lime industry and the difficulty of using existing ships.

### **Conclusions**

In conclusion, the potential of the device presented is therefore evident, especially in the field of renewable energy, as shown in the use in the biogas digester, in the separation of Syngas and in the capture of CO<sub>2</sub> from the air.

Obviously, by changing the assets and the dimensions it is possible to bring an advantage in many other industrial fields such as the food industry or the extractive industry, in which the use of this device allows for example to separate the components of bituminous shale, more and more operating at greater depths with products that are less and less pure. It can be used in both small and large plants and requires minimal maintenance, for example to clean the filters, set up before entering GSMF, necessary to ensure an adequate size of the suspended agents. It requires a low construction cost, given the materials that can be easily purchased on the market, but also a low cost of use. GSMF, thanks to its ease of construction and versatility as an N-phase gravimetric separator, can be designed and adapted to many industrial applications. Ultimately, GSMF presents a valid alternative to the many systems of separation of mixtures already present and existing, helping to reduce construction, maintenance and use costs while still managing to reach high levels of separation thanks to the reverse return characteristics.

### **Patent**

Lavanga V., Farné S., GSMF <https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2016092577>  
(gravimetric separator mixtures fluid, liquid and gas).

### **Declarations**

#### ***Source of Funding***

*This research did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.*

#### ***Competing Interests Statement***

*The author declares no competing financial, professional and personal interests.*

#### ***Consent for publication***

*Author declares that he/she consented for the publication of this research work.*

### **Bibliography**

Farné S., The Gravity Separation Mixture Fluid: An Innovative Method and Device to Separate the Components in a Gas, Liquid or Vapour Mixture, Asian Journal of Basic Science & Research, Volume 3, Issue 4, Pages 22-35, October-December 2021.

Farné S., Innovative Small Size Plant for the Production of Biogas and Electric Energy from Biomass, Middle East Journal of Applied Science & Technology (MEJAST), Vol.3, Iss.3, Pages 09-27, July-September 2020.

Farné S., Macchine. Macchine idrauliche. Synopsis, Libreria Universitaria Medea.

T. Ahmed, N. Makwashi e M. Hameed, A Review of Gravity Three - Phase Separators, Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 2017.

Charles Ross & Son Company, Mixing Equipment and Applications in the Food Industry.

Baker, J.R., 1991. Motionless mixers stir up new uses. Chem. Eng. Prog. 87, 32-38.

Maurice Stewart e Ken Arnold, Gas Liquid and Liquid-Liquid Separators, 2008.

Batchelor, G.K., The theory of Homogeneous Turbulence, Cambridge University Press, Cambridge, England 1953

Edward L. Paul, Victor A. Atiemo-Obeng, Suzanne M. Kresta- Handbook of Industrial Mixing - Science and practice, cap. 21-Mechanical Design of Mixing Equipment, 2004.

M. Mostafaiyan, Mohammad Reza Saeb, Alireza Emami Alorizi, Maysam Farahani -Application of evolutionary computational approach in design of horizontal three-phase gravity separators, Journal of Petroleum Science and Engineering, 2014.

Elhaj, M. E. M., & Adli, M. G. A. (2014). Influence of flow characteristics on the design of two-phase horizontal separators. Journal of Science and Technology, 15.

Akram Ghanem, Thierry Lemenand, Dominique Della Valle, Hassan Peerhossaini- Static mixers: Mechanisms, applications, and characterization methods – A review, Chemical Engineering Research and Design 92, 2014, 205–228.

[www.impianto.it/la-cattura-della-co2](http://www.impianto.it/la-cattura-della-co2).

[www.arpae.it](http://www.arpae.it) – Agenzia regionale prevenzione e ambiente dell'Emilia Romagna.