D15: Technical Considerations Part 3 - EUROSKIM

Work package No. 15:	**Technical considerations**
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1 EXECUTIVE SUMMARY

This report is the part 3 of the WP15 of the EUROLAKES general study.

Among other technical problems, the pollution by oil has proved to have very important economical and ecological consequences. It is very fortunate that the main accidents happen at sea which has higher self treatment capabilities than a lake, but the risks for such a pollution in lakes is not null.

Many accidents scenarios can be proposed. Oil can pollute the surface of the lake after a car or truck accident. Trains accidents can be a source of larger pollution, up to some hundred tons. Pollution from the water table can also come from industrial sites or gas stations. The worse case is probably the rupture of a pipe line which can pour thousand tons in a short period of time.

In general, the pollution in a lake will not be linked with extremely severe weather conditions, except in the case of a cargo ship wreckage. The weather conditions can be considered as calm compared to sea conditions when such accidents happen. The examples of Torrey-Canyon, Amoco-Cadix and more recently of ERIKA show that the sea state is almost always the trigger for such accidents, even though it is not the only reason in most cases.

The first means that can be utilized are the oil booms which are commercially available. They have to be installed very rapidly to prevent a larger extent of the nape. Typically, the intervention should be prepared in one hour and this means that all lakes should be equipped with such a barrier of about 1000 m long. Some recent models are very light and are used only once. They can work in moderate sea states and are well adapted to lakes.

To remove the oil thus contained, there exist some hydrophobic and oilophylic materials which can pump the oil as a sponge. These systems are available under the form of belts and are well suited for applications to industrial installations. In the same category are the surface static skimmers which can work only in perfectly calm weather conditions.

We have developed in more details the principle of Cyclonet which has been developed in the 70's by SOGREAH. It is now sold by NEYRTEC Environnement in Meylan, 38, France. This small system can be simply attached by a small ship hull and can be put in operation very rapidly.

We have recalled the principles of the system and proposed some improvements which increase the operating capabilities of the Cyclonet. The main proposal is to add a built in pump in the Cyclonet which enables it to work even at reduced speed or at rest.

The Cyclonet is able to treat a hydrocarbon layer at the surface skimming velocity of about 1 m^2/s. It is a system which is well adapted to localized pollution. A typical time to process a pollution of 10 000 m^2 (100x100 m) is one day operation. The system is able to work only under calm weather conditions.

For more important pollution and larger surfaces, it is necessary to use more powerful systems. Among these, the principle of a high speed surface skimmer has been proposed in 1974 by B. Valibouse and A. Bonazzi of NEYRTEC. The feasibility of the process has been verified at this time, but no integration development had been made.

We have studied an integration of this skimmer under the name of EUROSKIM. The principle is to install the skimming board on a high speed catamaran at 20 knots. The surface layer is lifted by the board to an height comprised between 1 and 3 meters. It is simply caught in a collector and sent by gravity to storage tanks integrated to the vessel.

We have made a detailed study showing that a good compromise for this system could be to use a 1.5 meter wide board. This enables to treat a surface of 15 m^2/s or 4 500 m^2 in 5 minutes. Taking into account necessary stops to empty the tanks, the system is able to process a mean surface of 25 000 m^2 per hour. Unfortunately, several runs are necessary to reduce the mean thickness of the layer at an acceptable level.

This system is probably too expensive to be installed at a specific lake site. It could be more interesting to develop a central site from which the vessel and its equipments could be transported by truck in reasonable periods of time. For example, many alpine lakes are sufficiently close from each other to permit this equipment sharing system.

To conclude, the protection of lakes against accidental oil spillage cannot be solved by only one system.

Local equipment should be available at each lake location. A good compromise could be to use a system including one oil boom, a pneumatic boat equipped with 2 cyclonets or hydrophilic surface skimmers, a small floating reservoir and a cargo ship to transport the mixture from the accident zone to a shore tank.

In case of a major accident, more powerful means could be shared between the lakes concerned at an international level. The "EUROSKIM" has been developed in the frame of this study. Due to its nautical capabilities, it could also be used at sea, thus increasing the possible shareholders.

It would certainly be necessary to have a crew attached to one such vessel. Due to the relative rarity of such accidents, the ship could be used to other tasks such as removal of solid pollutions on water surfaces, transportation and uses of liquid, oceanography and limnology studies etc..

The vessel could also be fitted with other oil recovery equipment like hydrophobic water skimmers or Cyclonet. These systems could of course be simply installed and removed.

The Catamaran presents good marine behavior and its flat deck permits a good optimization of surface uses, including the installation of cranes, winches and other equipments. This vessel of about 17 meters long and 7 meters wide can be a multipurpose basis for a number of activities.

All these system need special ancillary devices among whose static or rotating separators able to treat large quantities of oil on ships or onshore. Among these system, we present the high speed separator OPTISEP recently developed by Ylec Consultants under sponsorship of TOTALFINAELF for water-oil separation in production wells which is able to work at very high flow rates and low watercut values.

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2 INTRODUCTION

This report constitutes the part 3 of the study relative to technical aspects applicable to lakes. It is treats the removal of floating liquid pollution by artificial means. These liquids are supposed to be lighter than water and non miscible. The typical fluid concerned is the oil and gasoline.

Such pollution in lakes will always be limited in volume, but it may interest a large surface and create very negative environmental impacts, including of courses bird death, but also poisoning of fishes and pollution of algae and plankton.

Due to the relative small volume of the lake and its very high sensibility to such pollution events, this type of accident has to be processed very rapidly with relatively light means.

We discuss in this report of the most probable types of accidents that can pollute a lake and the conditions in which they can happen.

We propose a set of solutions to contain the pollution and others to recover the floating liquids.

Among the skimmers presented, some are already commercially available and some, like the Cyclonet enhanced with an axial pump or the EUROSKIM have been developed in the frame of the present study.

After a general discussion of sources typology and characteristics, we describe some of the existing equipment which are commercially available.

The last part of the study is devoted to the EUROSKIM, a high speed oil skimmer associated with a catamaran vessel and secondary processing equipment.

3 POSSIBLE SOURCES OF POLLUTION

3.1 POINT SOURCES

Foreword.

In most cases, the pollution by hydrocarbons in lakes will be the result of an accident. This may imply a ground transportation, such as a train, a truck or a pipe line. It can also be a tanker carrying oil or light chemical fluids through the lake. Finally, there may be diffuse pollution which come from leisure motor boats or fishing boats.

These sources are in general relatively easy to detect and most of them have no reason to happen with very severe wind or wave conditions.

Some orders of magnitude.

The level of pollution by accidental pouring of oil will always be characterised by a relatively low volume of hydrocarbons.

Some *scenarii* can be imagined and numbers can be proposed for each of them.

Type	Car, leisure boat	Truck	Train	Pipe line
Volume.	100 l	10 000 l	200 000 l	Up to 1000 000 l

Table 3-1: Typical of volume of oil for different types of accidents.

Considering a typical surface layer of about 1 mm at the beginning of the accident, the surface covered by pollution would range from 100 m^2 to 106 m^2.

After some time which depends of the type of oil, water temperature and atmospheric conditions, the layer may reach 0.1 mm, or even less. In that case, a major pollution event will create a floating nape whose characteristic scale is of some km^2.

Even in the case of a truck, which may contain 10 000 litres of oil, the pollution can interest a very broad zone.

Some aspects of lake pollution.

The chance of having an accident on the lakeshore is obviously important if one considers that most lakeshores are zones where the density of population is high. This implies a dense industrial and transportation density and accidents are likely to occur in these zones.

The second aspect is that the total quantity of released products is always limited, even in the case of a pipeline breakdown. Some thousand of tons will always be a maximum and this cannot be compared with major sea accidents like Torrey Canyon or Amoco Cadix where several hundred thousands of tons have been released in water.

These accidents will generally not be linked with extreme weather conditions. The probability to associate pollution with major tempest is only true for a ship or tanker accident. The consequence is that there is a chance for the oil to float on the surface and not to form droplets and be entrained by waves and currents.

The accidents will mostly happen near the shore or at the shore. This implies that the solutions be very rapidly installed. Even in the case of a boat accident, the distance to the shore is always limited and, due to surface drift created by wind, which may be of some centimetres per second or some hundred meters per hour, the pollution is likely to reach a shore within hours.

To conclude, it appears that the lake is very sensitive to such pollution by hydrocarbons and that an immediate action is mandatory.

The quantity of oil to treat will always be relatively limited to a maximum of some thousand tons. It can also be very diffuse in the case of motor boats.

Finally, the risks of pollution are not strongly linked with bad weather condition, except maybe road ice or fog which are very often associated with calm weather.

3.2 OTHER SOURCES

Other sources of pollution may come from the catchment area of the lake. Practically, two sources of pollution can be encountered.

The first source comes from rivers, canals and more generally from running waters. They can come from accidents, for example from the river. They can also come from heavy rain events against which the sewage treatment plants are very often inefficient.

The second source is from underground waters. In that case, the pollution lasts for a very long period, whatever its origin. If no special measures are taken, this type of pollution can feed the lake with large quantities of pollutants. It is always a diffuse pollution.

It seems difficult to have practical actions when the pollution has reached the lake, but some treatments of the nape are likely to give good results.

We will discuss on some of these techniques and especially of underground hydraulic barriers to protect the lake from such pollution.

3.3 SYNTHESIS

Figure 3-1 gives a sketch of possible oil pollution sources on a lake.

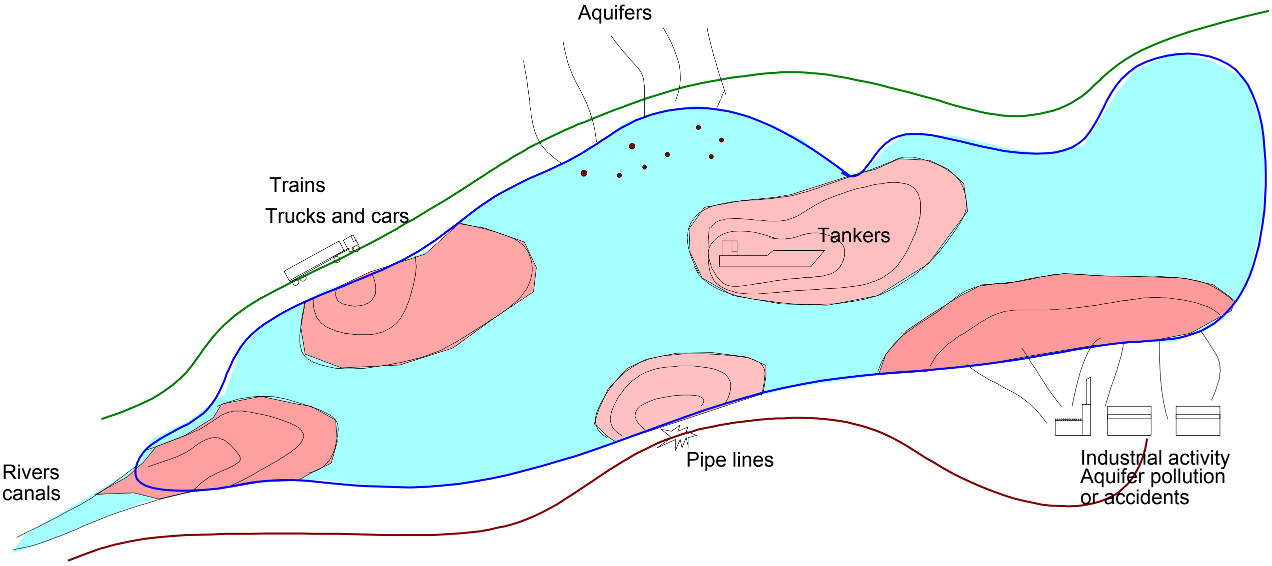

Figure 3-1: Possible oil pollution due to human activity around the lake.

These pollutions are only due to hydrocarbon release in the lake or its catchment area. These products are supposed to be immiscible in water and this makes it possible to recover them by skimming and separation or to reduce the spreading by adapted means.

One of its major characters is that such products naturally spread very rapidly, say within one day and that the consequences are extremely negative. A minor amount of pollution may interest square kilometres if nothing is done in due time.

Even though such accidents do not happen very often, there consequences on a small body of water such as a lake can be important enough to think of practical means to reduce their ecological and economic impacts.

4 EXISTING TECHNIQUES

4.1 FLOATING BARRAGES OR OIL BOOMS

In case of local pollution, there exist a technique which has been widely studied during the 70's and which is normally used to prevent the extension of pollution at sea or on lakes, ponds and rivers.
These barrages are generally made of floating inflatable cylinders below which is installed a more or less complex skirt.

Figure 4-1 gives a sketch of such a barrage.

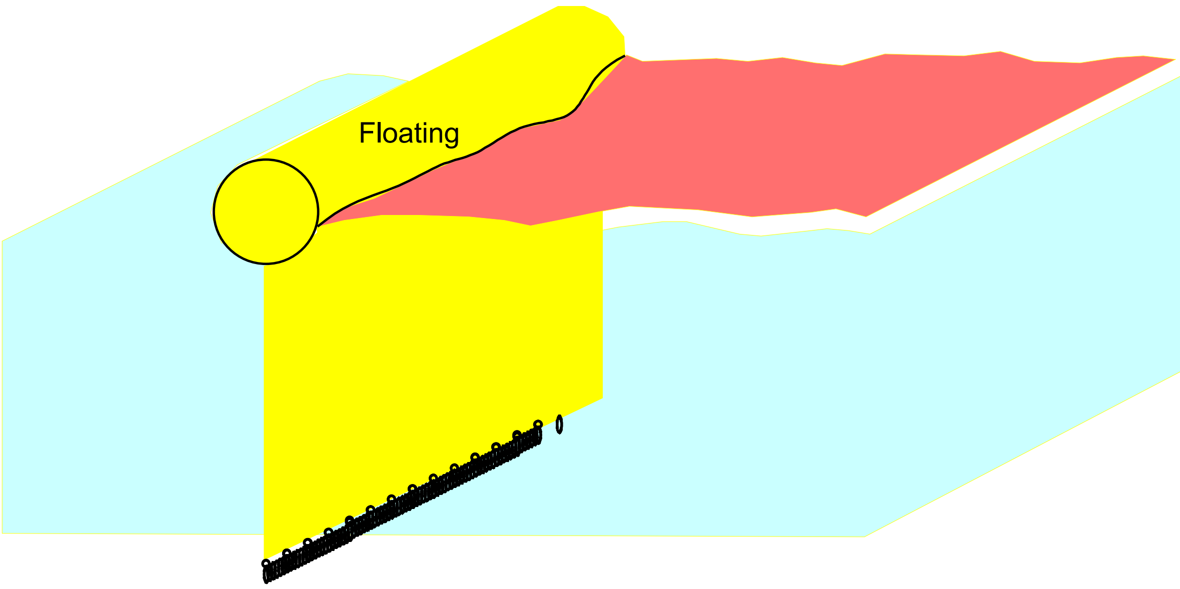

Figure 4-1: Principle of an oil boom.

From a technical point of view, the major difficulty is to adapt the stiffness of the barrage so that it can follow the waves but do not collapse.

Generally speaking, the floating cylinder is made of parts of limited length linked together and inflated with air. The weight is very often made of a chain. It creates a vertical force that help to maintain the skirt vertical.

The barrage can be prepared on land and slowly tugged by a ship to contain the polluted area. The typical length of such barrages is of some hundred meters and they are commercially available in Europe and United States.

Such booms must be installed immediately after the occurrence of the spill. Any delay in their installation will lead to an unavoidable spreading which occurs at typical velocities of some centimetres per second or some hundred meters per hour. The necessary length of equipment very rapidly change from hundred meters to kilometres.

Figure 4-2 gives an example of such a light oil boom from Lamor in Finland.

Figure 4-2: Lamor Ultralight Oil boom.

Practically speaking, any lake should be equipped with such a boom so that rescuers can be on spot within less than one hour.

The oil boom is the only system that can prevent spreading of pollution on the water.

They can also be used as permanent protections around sensible locations such as chemical plants or oil terminals.

The maximum velocity at which a boom can sustain oil is of about 1 knot (0.5 m/s). This means that they have to be manoeuvred with much care.

Except for very large oil booms, they cannot be used with high waves. In the case of lakes, care should be taken on the analysis of wave data before choosing such a device.

4.2 STATIC SKIMMERS

Several companies have developed static skimmers which are able to withdraw oil from a still water surface. These systems are of common use on ponds of refuse water from industrial activity and are also commercially available.

Figure 4-3 gives a sketch of such a system.

The oil floating on the free surface goes to the main reservoir over a weir. This is made possible by the operation of a water pump.

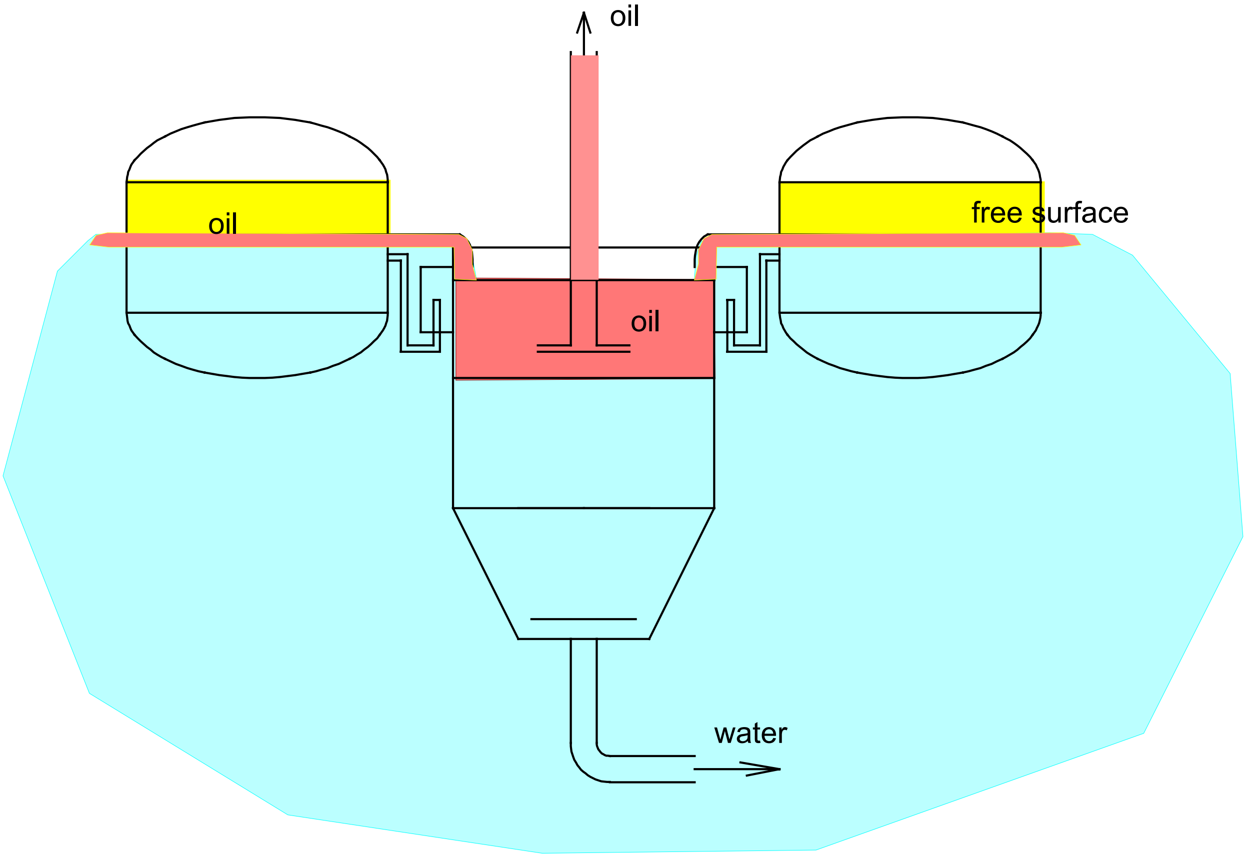

Figure 4-3: A static oil skimmer.

Separation occurs in the reservoir and when the thickness of the oil is high enough, it may be pumped by the oil pump.

Some surface skimmers use some special devices to maintain the level of the weir at a given altitude.

It is obvious that such systems can work only in calm water where they can be very useful. For example, in case of a localised pollution, they can take rid of the oil contained inside an oil boom provided the thickness of the oil layer is enough.

If large surfaces are to be processed, it is necessary to install several systems. The typical radius around a static skimmer is of some meters.

4.3 OTHER SYSTEMS

The other type of skimmers uses oilophylic substances which are immersed in the fluid. When they cross the interface, the products tend to retain some oil and to leave the water in place. Their mode of operation can be compared to a classifying sponge.

The oilophylic products are generally under the form of fibres.

They are arranged under the following forms :

- Belts,
- Drums,
- Disks

In each case, the system rotates. The oil is absorbed at the water surface. It is conveyed upwards and passes in a squeezer where the oil can be separated.

Figure 4-4 gives a sketch of an oil skimmer and separator developed by Lamor.

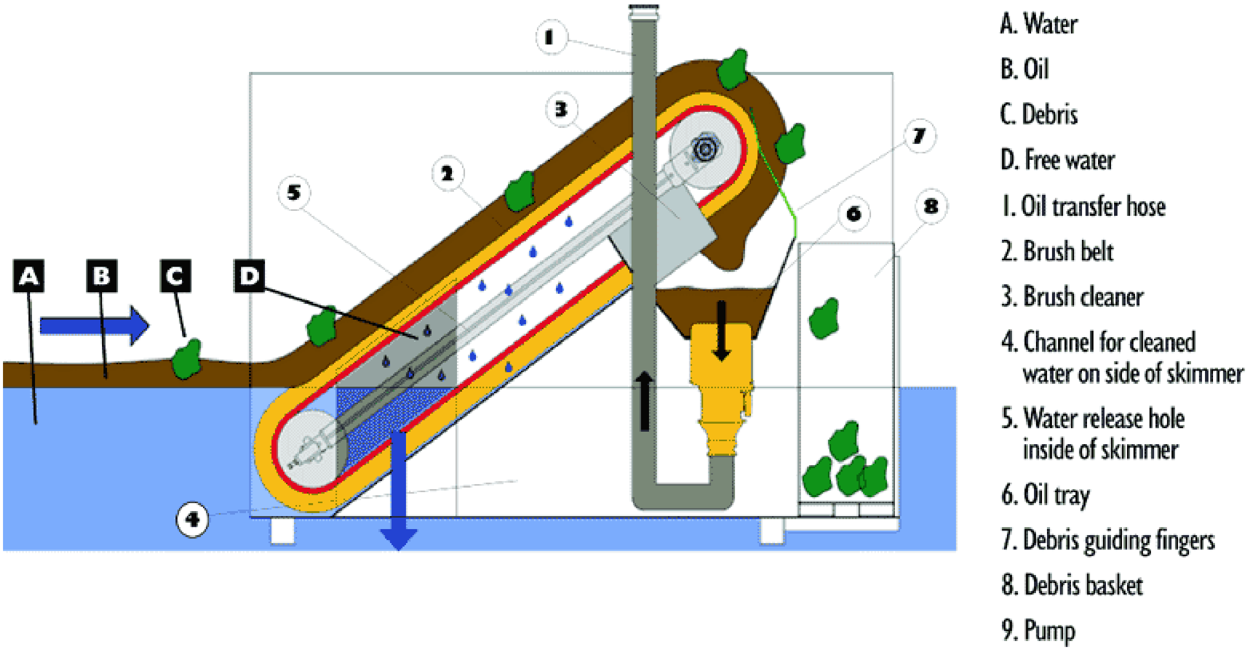

Figure 4-4: Lamor oil skimmer. principles.

On Figure 4-5 is given another example of a skimmer developed by Ro-cleandesmi in united states. They use loose belts impregnated with oilophylic products. The system is installed on customised vessels.

Figure 4-5: Ro-cleandesmi skimmer.

Based on the same principles, it is also possible to throw floating devices at the water surface. These floating balls are also coated with oilophylic fibres. They tend to absorb the oil by contact. They can be picked by boats with the help of nets or specialised skimmers.

Finally, most skimmer builders propose a ship adapted to the use of their products. Due to a number of reasons, the catamaran is in general the best solution for high capacity systems.
Figure 4-6 gives a sketch of such a catamaran developed by Lamor.

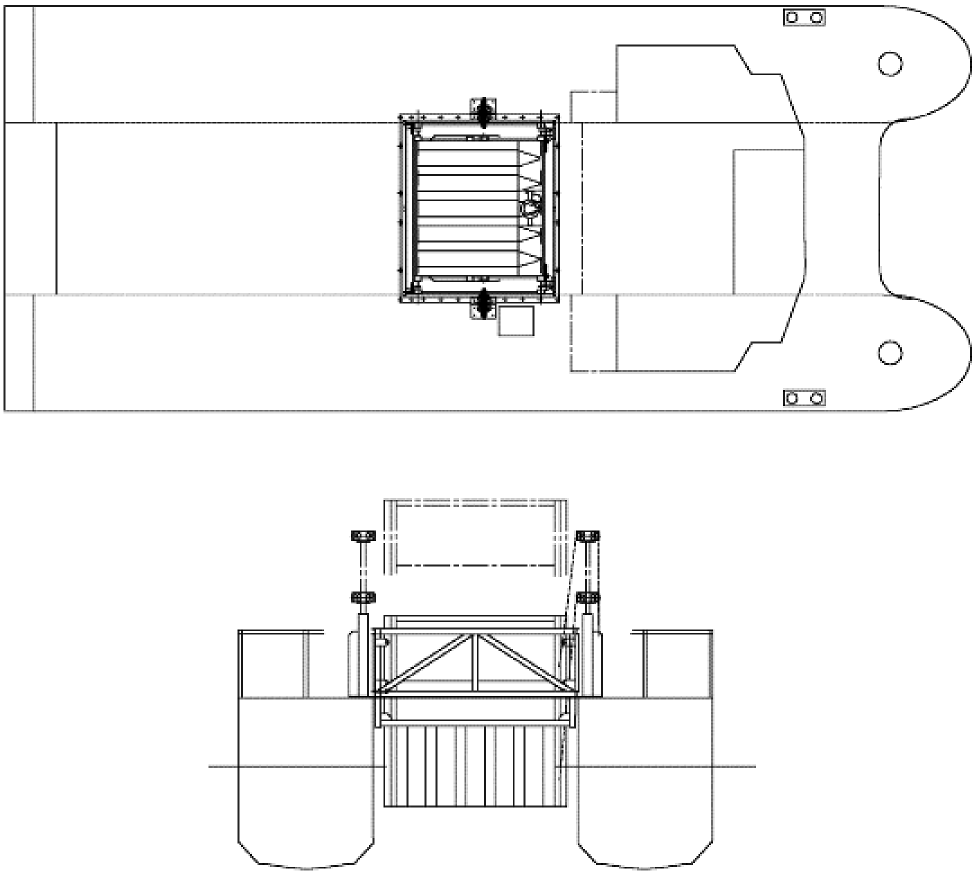

Figure 4-6: Lamor Catamaran.

All the above pictures and information are available on Internet sites of the builders cited.

4.4 THE CYCLONET

The basic system.

In order to be able to skim rapidly large surfaces of liquid, it seems useful to use moving skimmers. Some examples of such system have already be described above.

The Cyclonet has been developed by SOGREAH in 1974. It is a combination of a skimmer linked to a cyclone. The principle is that the skimmed oil and water enter tangentially in a cylinder. Due to this tangential inlet, a rotating flow is produced. This permits the separation of oil and water under the effect of a weak centrifugal force. The order of magnitude of the corresponding acceleration is of about 1 g (9.81 m/s^2).

The combination of the centrifugal acceleration and the gravity acceleration makes the oil to aggregate towards the centre of the separator and to raise at its top. A more or less conical volume of oil is produced in the cylinder. This mixture can be pumped by a positive displacement pump. The remaining part of the water escapes through the outlet of the cyclone which is placed at the tip of a cone placed below the separation cylinder.

The system can be installed near the hull of a ship and is relatively easy to install. A sketch of this apparatus is given on Figure 4-7.

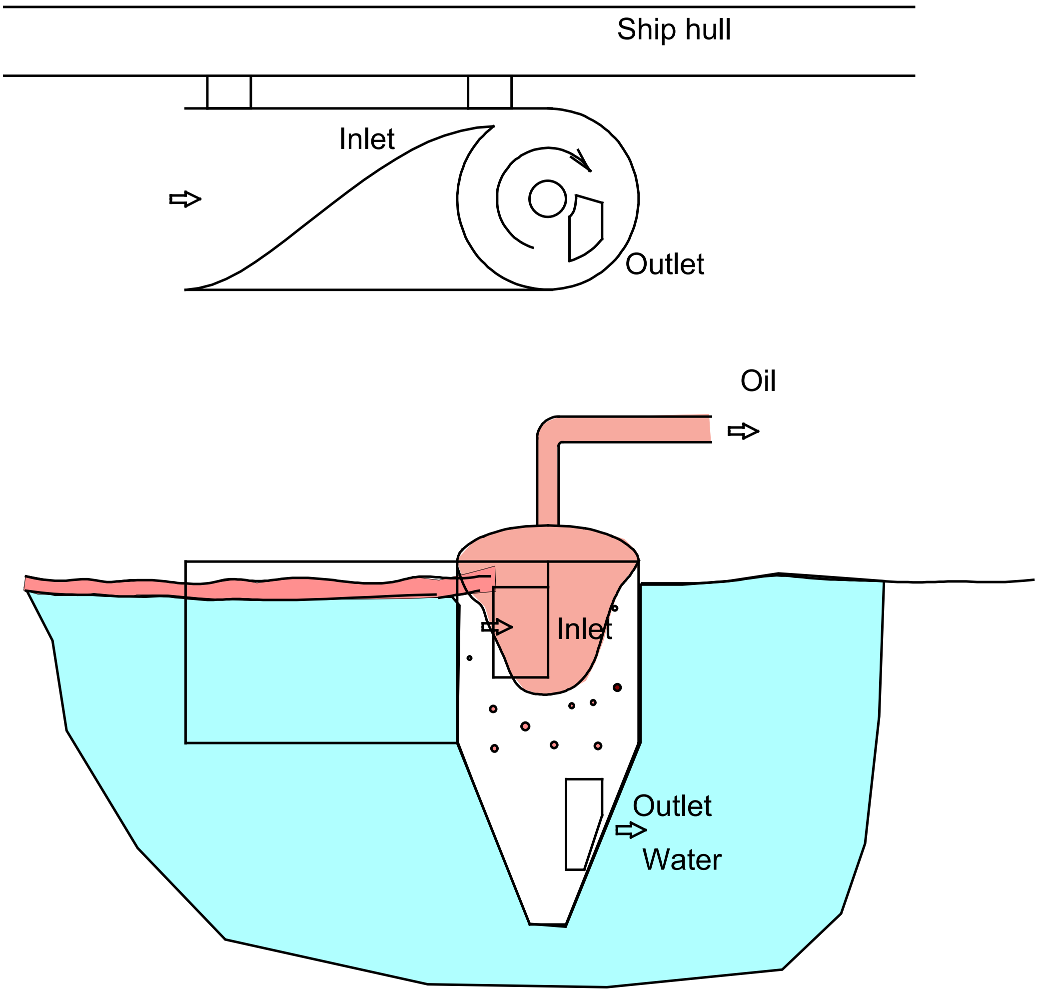

Figure 4-7: Cyclonet, principles.

Various models of this basic system have been developed in the 70's years by SOGREAH. Among these, the 500 mm Cyclonet could be installed on the two sides of a pneumatic boat. At the speed of 2 knots (1 m/s), it was possible to treat a surface of 1 m^2/s or 3600 m^2/hr (60x60 m). After one day, the skimmed surface is of 90 000 m^2 (300x300 m).

If the mean skimmed thickness was of 1 cm, the volume of emulsion to store had to be of 900 m^3 per day (10 l/s).

The oil and water skimmed could be pumped in a soft tanker tugged by another boat. When empty, such a tanker can be transported in a truck. The emulsion could also be stored in a conventional small tanker where processing was likely to be made.

This system is well suited to process a spill of oil in water on relatively small surfaces. It proved to be relatively efficient even on crude oil at sea.

Its key feature is that the pumping occurs just after the inlet in the separator where the velocities are small enough to prevent any extra emulsification of the mixture. Compared to other skimmers, it is able to collect an emulsion with relatively low water-cuts.

Despite the good results obtained with this small device, the French administration decided not to go further in the development. At that time, the theory was that chemical dispersion was a better way to treat oil spills.

This conclusion is controversial, because pollution problems may arise after chemical treatments. The consequence is that the practical solution is to wait for natural dispersion of the oil spill, at least in the case of sea wreckage and to treat by hand the polluted sea shores. The recent wreckage of Erika is a perfect illustration of this policy.

This can be the only way to proceed at sea, especially when the weather conditions are bad, which is generally the case. It would probably be less acceptable to let the things go the natural way in a lake due to the relatively small volumes and surfaces involved.

Possible enhancements.

The principle of the Cyclonet was to run only because of its own velocity. This makes it very simple to use, but the performances are not always optimised at any velocity.

It seems that it could be possible to use it as dynamic skimmer if a low head pump was added to the water exit.

The solution, which has been studied by Ylec Consultants, is presented on Figure 4-8.

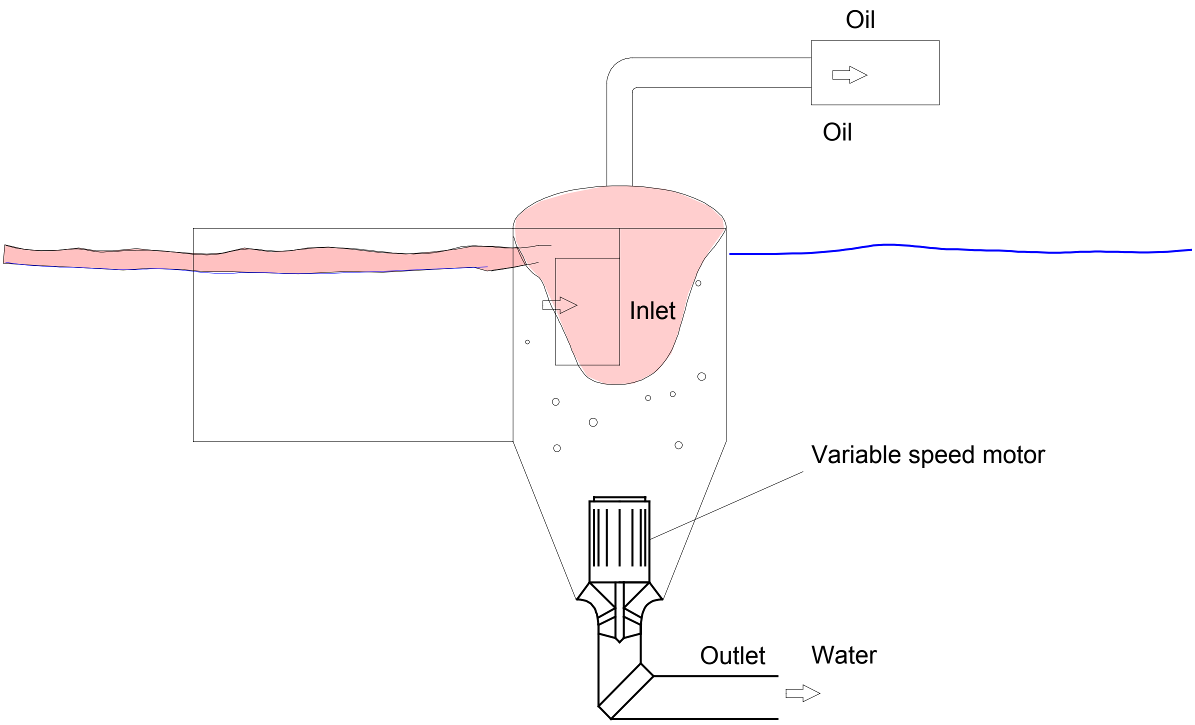

Figure 4-8: Installation of a pump in a Cyclonet.

This would permit to use the system at any velocity, including when the carrying boat is at rest. This enhancement would of course make the Cyclonet more versatile and practically much more easy to use.

For an application to lakes, the system could be installed inside a closed boom and could operate in the zones where the thickness of the nape is at maximum. It could also operate in shallow water and in places where the boat manoeuvrability is difficult.
Due to the limited volume of oil to process, a small size Cyclonet could be enough. In our opinion, it could be possible to develop a system with 2 Cyclonets of 500 to 800 mm in diameter each.

They could be easily stored in a hangar together with an oil boom and a soft floating tanker.

They should be operated by a trained team capable to reach the accident within one hour. This means that at least one such global system should be installed on each lake. For larger lakes, a typical distance between 2 sites should be of one hour boating (5 to 10 miles).

The limitations.

Obviously, the limitations of the Cyclonet are the presence of waves. A typical value for this limitations is that the wave height do not exceed one third of the Cyclonet diameter at a wave length smaller than 2 times the length of the Cyclonet. This is already a relatively high sea state and this means that this system is well suited to operate on a lake.

The other limitation is that the nape of oil is formed again after the passage of the skimmer. This means that the mean decrease of the oil thickness is proportional to the thickness itself.

In other terms, if S is the surface of lake to be treated and e the mean thickness of oil; if L is the breadth of the surface skimmed by the Cyclonet and U the advance velocity, one can write :

The flow rate of oil removed :

$$q = LUe$$

the decrease of the mean thickness :

$$-S\frac{de}{dt} = q$$

combining the two above equations leads to :

$$-S\frac{de}{dt} = LUe$$

or :

$$\frac{de}{e} = -\frac{UL}{S}dt$$

The solution of this equation is :

$$e = e_0\ e^{-\frac{UL}{S}t}$$

For example , for an oil spill of 1 cm on a surface of 10 000 m^2, using a Cyclonet with a width of 1 m will permit to reach a residual thickness of 1 mm after a time of :

$$t = \frac{S}{UL}\mathrm{Log}\frac{e_0}{e}$$

Or :

$$t = \frac{10000}{11} \mathrm{Log}10 = 23000 \text{ s}$$

The time needed to remove most of the initial pollution of 100 tons is of about 6 to 7 hours.

6 to 7 extra hours will theoretically permit to reach a thickness of 0.1 mm. Of course, this type of treatment should be linked to a reduction of the surface S by moving the oil booms.

Another drawback of the system is its vulnerability when it is submitted to rough weather conditions. When waves are formed, the forces acting on this body of equipment are rather large and this limits the operational capability of the system.

This is why a Cyclonet equipment should include means to lift the skimmers out of water. If the system is installed on a pneumatic boat, which would be recommended for application to lakes, the Cyclonet is of small size and it may be lifted by hand.

If it is installed on a larger ship, hydraulic equipment will be needed to immerse and withdraw the system.

4.5 ANCILLARY SYSTEMS

Lifting surfaces.

The surface layer of oil is often very thin and, as shown above, the time needed to make it disappear is rather long. It may be interesting to consider some hydrodynamic systems to thicken this layer and enhance the recovery rate.

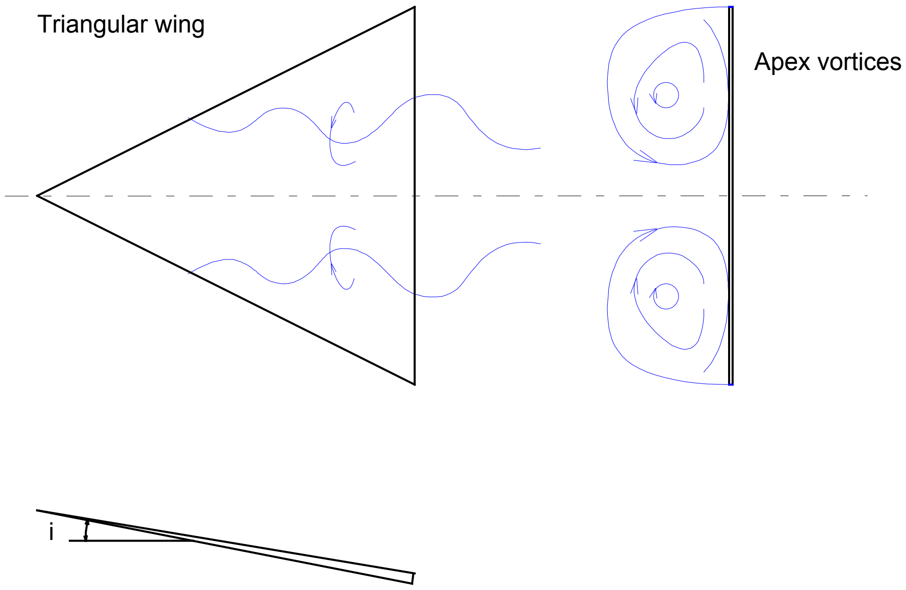

Figure 4-9: Principle of a triangular lifting surface.

Among these systems, it is possible to use ship bows in the shape of an axially symmetric lifting surface. The lift creates a circulation which is directed towards the axis of the surface.

If the surfaces are adjusted on a ship hull, the vortices are directed towards the hull. The hull behaves like a wall and the oil is stopped. This phenomenon tends to increase the thickness of the oil layer.

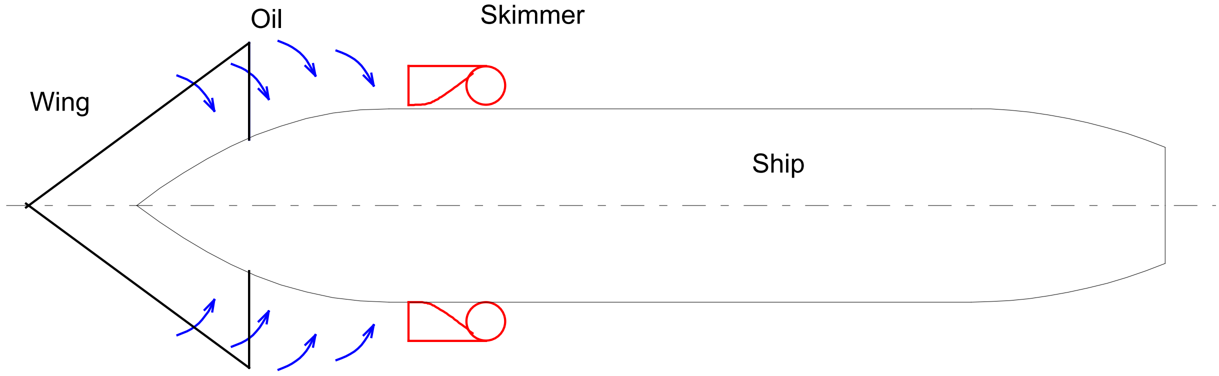

Figure 4-10: Hydrodynamic thickener of oil layer.

If the moving skimmer, like a Cyclonet is installed by the hull, it will be likely to skim more oil than it would without the lifting surface.

The system has proved to be very efficient, but it seems to be more efficient for sea applications where the size of ships needed to remove pollution is much larger than in lakes.

Ship as a wave absorber.

The main limitation of the Cyclonet is the presence of waves. A solution to reduce the amplitude of waves is to use a large ship running as close as possible of the ship carrying the skimmer and advancing in a direction perpendicular to the waves.

This permits to reduce dramatically the wave amplitude and it is relatively easy to use. In case of oil spill, several lake boats can be used for this purpose.

4.6 THE USE OF SKIMMING BOARDS

The detailed description of a planning board will be given in the following. It should be noted that this idea has recently been developed by R Latorre from New Orleans university with a skimmer called the water blade[1].

A sketch of this subsurface, non planning system is shown on Figure 4-11.

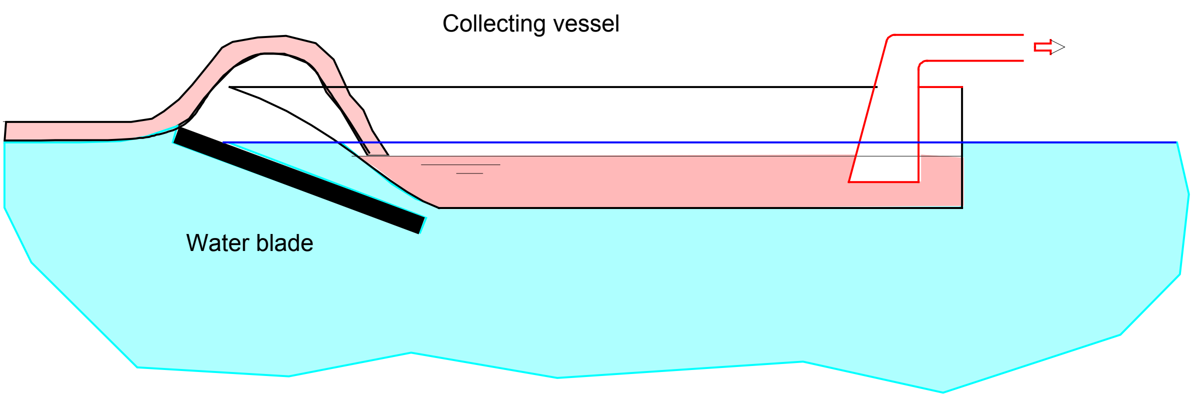

Figure 4-11: The water Blade.

This concept is interesting, but the blade has to be firmly supported and is not self stabilising.

A second concept developed in NEYRTEC consists to use skimmers made of honeycombs as shown on Figure 4-12.

[1] Dr R. Latorre, Development of water blade to remove oil-water surface layer by moving boat. J. Marine Env. Engg. Vol 1. pp 111-117. 1994

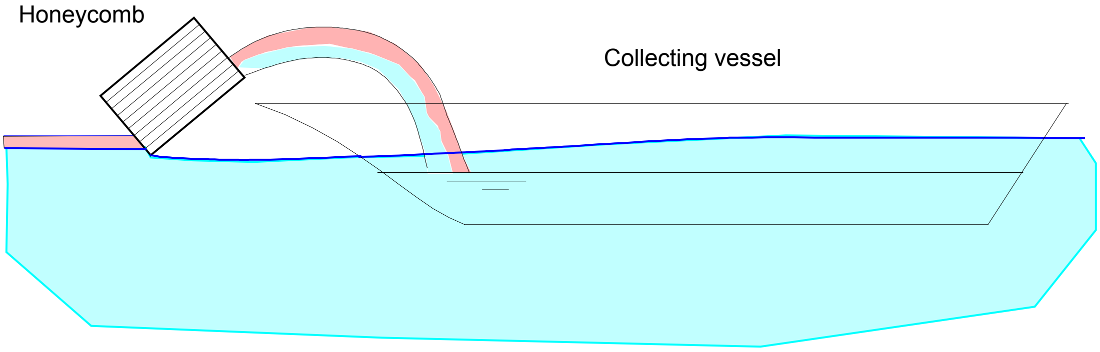

Figure 4-12: Honeycomb skimmer. NEYRTEC

This honeycomb proved to be very efficient. It has been tested with oil and water in a towing tank. The major drawback to its utilisation is its instability. It tends to sink when the water levels rises. This implies high mechanics loads to keep it in position.

5 TYPICAL DIMENSIONS OF A CYCLONET

5.1 SPECIFICATIONS

In the case of lakes, a good order of magnitude of an oil spill could be of around 100 tons, as already said above. This corresponds to a train accident.

The procedure will always be the following :

1. Install an oil boom.
2. Use a skimmer inside the surface protected by the boom.
3. Store the skimmed emulsion first in a floating tank.
4. Transport the emulsion to land.
5. Treat the emulsion to separate oil and water.
6. Treat both the separated oil and the water.

As we said above, a good order of magnitude could be to use a twin Cyclonet, each item being installed by the hull of a pneumatic boat. The speed of the system could be of about 1 m/s. Consequently, the width of water skimmed would be of 1 meter, each Cyclonet having a diameter of 500 mm.

It has been shown that such a system would be able to take rid of 100 tons of oil on a surface of 10 000 m2 with an initial thickness of 1 cm.

5.2 DIMENSIONS OF EACH CYCLONET

For application to lakes, the skimmers must be small and easy to operate. It has been shown that the quantity of oil to recover is always limited. 100 m^3 is a good order of magnitude for a major spillage.

The basic diameter of the shimmer will be of 500 mm.

The principle is that the gravity forces must have an effect comparable to the centrifugal forces.

It is well known that the centrifugal acceleration is given by :

$$\gamma_c = \frac{U_T^2}{r}$$

The Cyclonet behaves like a conventional cyclone.

Without going too deep in the theory of such separators, the numerous tests made by researchers show that in the region comprised between the inlet and the water exit, the tangential velocity tends to increase and to reach a maximum. The rate of increase is given by :

$$\frac{U_T}{U_{T1}} = \left(\frac{r_0}{r}\right)^n$$

The order of magnitude of the n exponent is of 0.7.

Moreover, the mixing at the cyclone inlet tends to reduce the initial velocity U_{T0} to a value U_{T1} which is of about :

$$\frac{U_{T1}}{U_{T0}} = \alpha = 0.8$$

Thus the velocity distribution can be written :

$$U_T = 0.8\, U_{T0} \left(\frac{r_0}{r}\right)^{0.7}$$

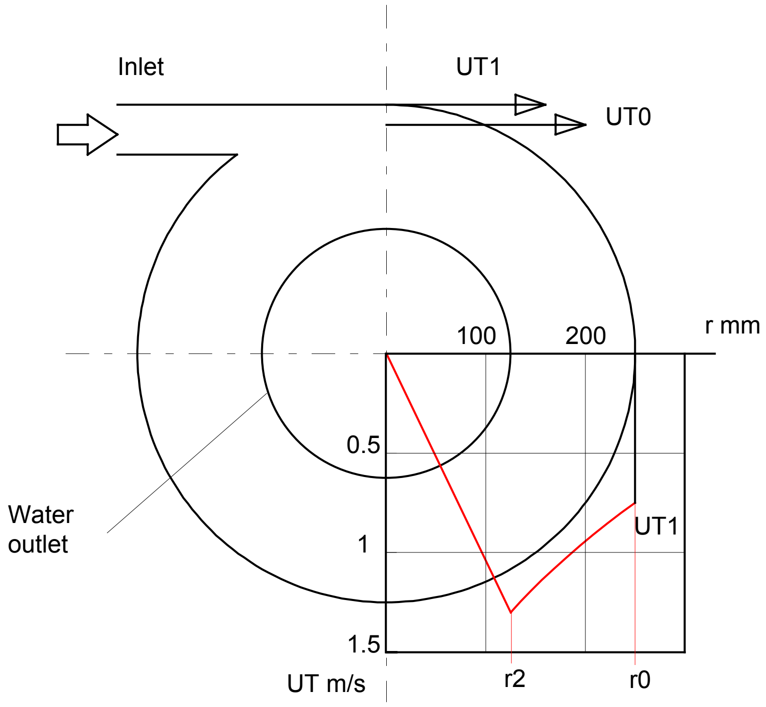

Figure 5-1: Velocity distribution in a cyclone.

For example, in the case of the Cyclonet represented on Figure 5-1, the tangential velocity at the water exit (r_2) is equal to :

$$U_T = 0.8\, U_{T0}\left(\frac{r_0}{r_2}\right)^{0.7}$$

And if r_2=0.5 r_0,

$$U_T = 1.3\, U_{T0}$$

The centrifugal acceleration at this point is of :

$$\gamma_{c2} = \frac{U_T^2}{r_2} = 1.69\frac{U_{T0}^2}{r_2}$$

If U_{T0}=1 m/s and r_2=0.125 m, one finds :

$$\gamma_c = 13.5\ \text{m/s}^2$$

This is the point of maximum acceleration. After this point, the velocity distribution decreases linearly :

$$U_T = 1.3\, U_{T0}\frac{r}{r_2}$$

And

$$\gamma_c = \frac{U_T^2}{r} = 1.69\frac{U_{T0}^2}{r_2}\frac{r}{r_2} = \gamma_{c2}\frac{r}{r_2}$$

At the point 2 of maximum acceleration, the two possesses of gravity and centrifugal separation should be of the same order of importance.

This means that the velocity of 2 kn is well adapted for the operation of the system. At higher speeds, the diameter of the water exit should be larger. This may be done by installing outlets of higher diameter.

5.3 FLOW RATE

The flow rate in the system must be much higher than the oil flow rate.

As we have already seen, the maximum flow rate of oil may correspond to an oil layer thickness of 10 mm. The corresponding flow rate of oil of 5 l/s.

The total flow rate of mixture passing in the skimmer could be of 5 to 10 times this value, which means 25 to 50 l/s.

The velocity U_{T0} is of 1 m/s. This permits to calculate the height of the entrance the width of which will be of 50 mm. This gives a height of 500 mm for a flow rate of 25 l/s.

The pump used to extract the water will have a flow rate of the same order of magnitude. It will be used when the carrying boat is stopped or will force the flow rate at low velocity of the boat.

5.4 INSTALLATION ON A BOAT

The system must be very easy to use and the time for installation as short as possible, for example less than ½ hour.

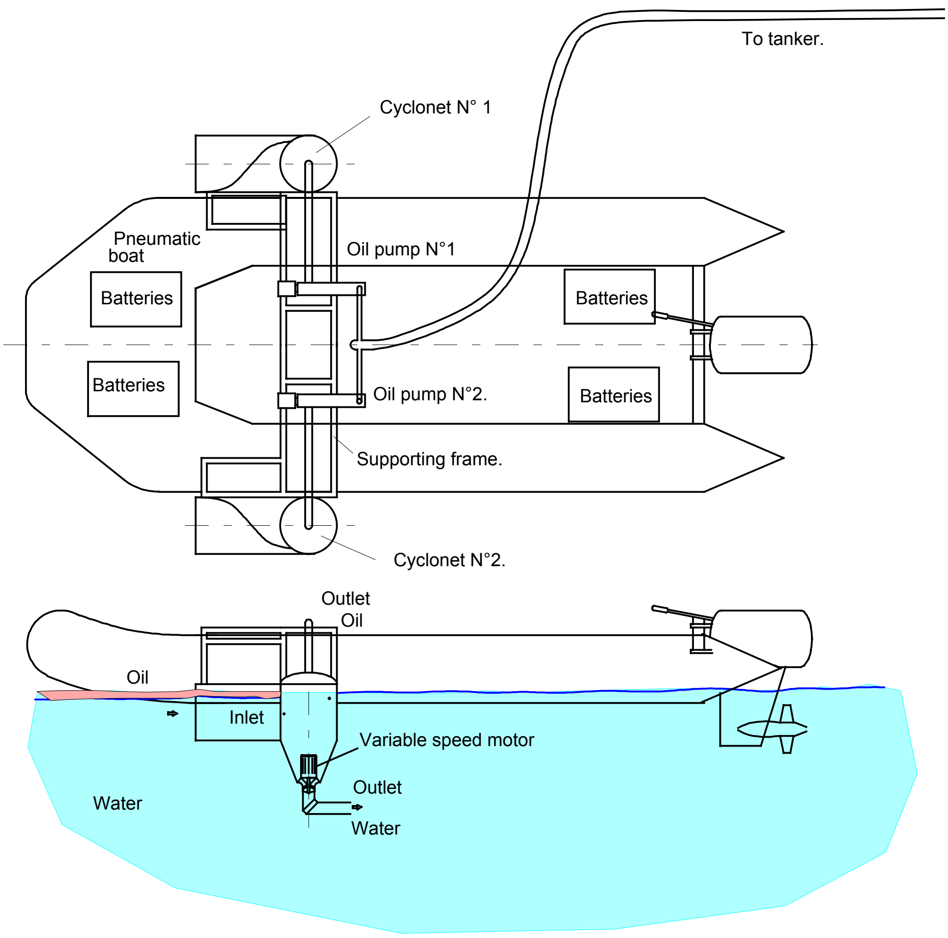

Figure 5-2: Installation of two cyclonets on a pneumatic boat.

The project is based on 2 cyclonets of 500 mm each.

These cyclonets are installed on a pneumatic boat of about 6 m long.

The system is presented on Figure 5-2.

As all the components must be ADF (Electric spark free and heat free), all the rotating machinery has to be fed with electric batteries. These components are the two oil pumps, the two water pumps and the propeller. This is an important part of the total weight.

The weight of one single Cyclonet without pump is of 80 kg. The total weight of the parts to install on the pneumatic boat has been evaluated at 300 to 500 kg, including batteries.

The pneumatic boat to use should be able to transport about 1 Ton.

6 THE EUROSKIM

6.1 FOREWORD

The Cyclonet is a skimmer which can be used with a limited pollution. In case of more important spillage, greater than some hundred tons, the time needed for recovery would be too long and a faster system is needed.

The problem associated with the Cyclonet is that it can hardly work at a speed higher than 2 or 3 knots. This is due to the drag induced by the skimmer which is totally immersed and not hydrodynamically shaped. The problem is even worse in waves and the oscillatory forces acting on the system can destroy it.

To solve these two problems, it was thought interesting to develop a high speed surface skimmer.

The original idea has been developed in 1981 by Valibouse and Bonazzi in NEYRTEC[2].

The principle was to use the phenomenon observed with water skiing. When the water skier turns, he lifts a layer of water which is very spectacular. This layer reaches typical heights of 1 to 2 meters.

A careful analysis of the flow below the ski shows that the plane of water is made of a thin layer escaping from the free surface.

The system is extremely interesting for many reasons :

- There are no immersed devices.
- The stability is automatic.
- The thickness of the layer removed can be adjusted by changing the width of the board and its angle of attack.
- The system is able to work at high speed, typically of more than 10 knots.
- The system can work in relatively agitated water.

For this reason, some studies regarding the principles and performances have been undertaken by Neyrtec in the eighties.

Our purpose is to show its applicability to remove oil at the surface of lakes.

6.2 PRINCIPLES

[2] Valibouse, Bernard, Bonazzi, Albert. Dispositif de ramassage de produits flottants sur une étendue liquide. European patent 81104056.7

The basic principle of the system is given on Figure 6-1.

The planning board is moved at a velocity U. The water flow is divided in two parts limited by the line AB. Point B is the stagnation point on the board

The upper part of the flow is projected upwards. It leaves the plate at the plate angle and at relative velocity equal to the velocity of the plate relative to the water.

The surface layer is skimmed by this movement and it is shown that if this layer is deep enough, the board is always in contact with water, thus preventing excessive friction.

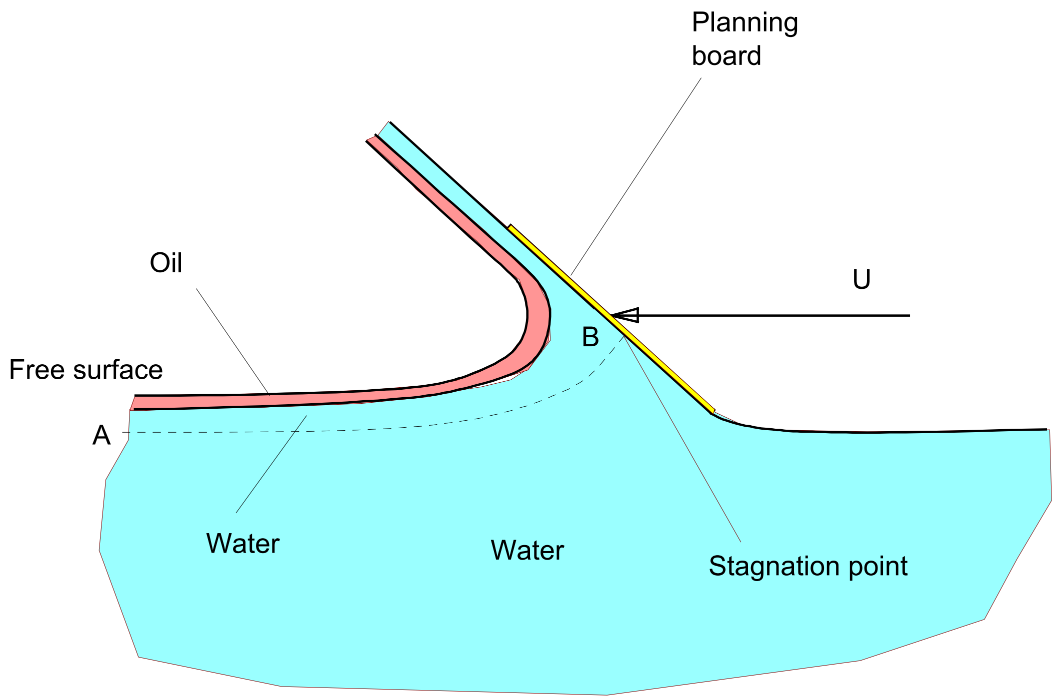

Figure 6-1: Principle of the Vitecope (EUROSKIM)

The important point is that the whole system behaves as if there was no oil which acts only by its inertia. As the specific mass of oil is very close to the specific mass of water, its inertia is very similar. Consequently, the whole problem can be calculated as if there was only water.

Practically speaking, the height of skimmed layer will be of some millimetres to some centimetres. A good order of magnitude is to skim one to two centimetres.

6.3 ELEMENTARY APPROACH OF THE PROBLEM

The following notations will be used :

- α is the angle of the plate with the horizontal plane.

- l is the width of the plate.
- δ is the thickness of the water jet.
- y_0 is the depth of water ahead of the plate.
- h is the elevation of the downstream of the board.
- b is the width of the board perpendicular to the advance velocity.
- e is the immersion of the plate.

The first obvious point is that b must always be smaller than y_0. The board has to touch the water to skim.

The fluid can be considered as perfect. This means that its energy remains constant.

In the region of the board, the effects of gravity will be neglected at first.

The scheme of the flow and the notations are given on Figure 6-2.

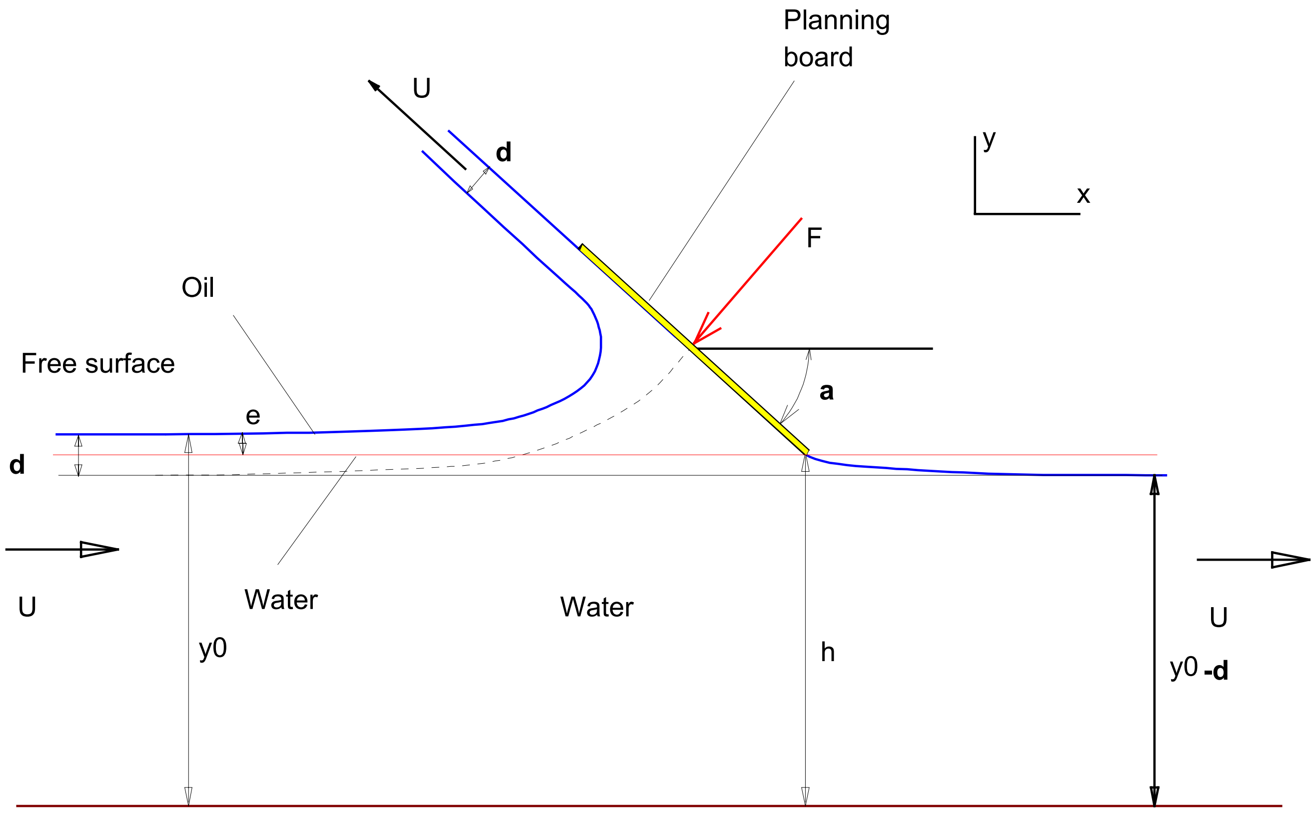

Figure 6-2: Scheme utilised for calculation.

All the streamlines leaving the plane have the same velocity U. The direct consequence is that the depth of water skimmed is equal to the thickness of the jet, δ.

This means that the point C is always very near from the surface and that this cannot be controlled. The only practical control is the weight applied to the board. For this reason, we must calculate the forces acting on the plate due to the flow.

The only force acting on the plate is directed in the direction perpendicular to it. The value of that force is readily calculated by application of the theorem of conservation of momentum.

$$\vec{F} = \Delta(\rho q \vec{U})$$

The component of the force towards x is given by :

$$F_x = \rho U^2 y_0 b - \left(\rho U^2 (y_0 - \delta) b - \rho U^2 \delta \cos\alpha \, b\right)$$

or : $F_x = \rho U^2 b \delta (1 + \cos\alpha)$

The force acting on the plate is given by :

or : $F = \frac{F_x}{\sin\alpha} = \rho U^2 b \delta \frac{1+\cos\alpha}{\sin\alpha}$

These two equations show that if U, F and α are known, the thickness of the later removed is perfectly known and is given by :

$$\delta = \frac{F_x}{\rho U^2 b} \frac{\sin^2\alpha}{1+\cos\alpha}$$

Or, if F_y is the vertical component of the force acting on the board :

$$\delta = \frac{F_y}{\rho U^2 b} \frac{\mathrm{tg}\ \alpha}{1+\cos\alpha}$$

The practical variation of α is limited to about 45° to 60°.

We have calculated the value of δ versus the vertical force applied for three different values of α. The results are given on Table 6-1.

FY N	U m/s	α °	b m	α rad	δ	q m³/s	q l/s
1000	5	30	1	0.52	0.0124	0.0619	61.88
1000	7.5	30	1	0.52	0.0055	0.0413	41.25
1000	10	30	1	0.52	0.0031	0.0309	30.94
1000	12.5	30	1	0.52	0.0020	0.0248	24.75
1000	**5**	**45**	**1**	**0.79**	**0.0234**	**0.1172**	**117.16**
1000	**7.5**	**45**	**1**	**0.79**	**0.0104**	**0.0781**	**78.10**
1000	**10**	**45**	**1**	**0.79**	**0.0059**	**0.0586**	**58.58**
1000	**12.5**	**45**	**1**	**0.79**	**0.0037**	**0.0469**	**46.86**
1000	5	60	1	1.05	0.0462	0.2309	230.94

1000	7.5	60	1	1.05	0.0205	0.1540	153.96
1000	10	60	1	1.05	0.0115	0.1155	115.47
1000	12.5	60	1	1.05	0.0074	0.0924	92.38
500	5	45	1	0.79	0.0117	0.0586	58.58
500	7.5	45	1	0.79	0.0052	0.0391	39.05
500	10	45	1	0.79	0.0029	0.0293	29.29
500	12.5	45	1	0.79	0.0019	0.0234	23.43

Table 6-1: Thickness of the skimmed layer and associated flow rate for a board of 1 m wide.

The same results are given on graphical form for the three angles of attack considered.

It should first be noted that thickness δ depends only on three parameters, the velocity U, the weight F_y and the angle of attack α. Typical values of δ are of some millimetres and this is exactly the range of thickness to process.

Secondly, it is very important to consider the fact that the vertical force increases when the depth of immersion increases. The system is automatically stable and this is extremely important in waves.

Finally, the thickness of the skimmed layer depends on the angle of attack. This means that it can be simply adjusted at constant velocity. It also means that there will be a slightly varying thickness skimmed when the system crosses waves, but the variation will not be very important if these waves do not brake.

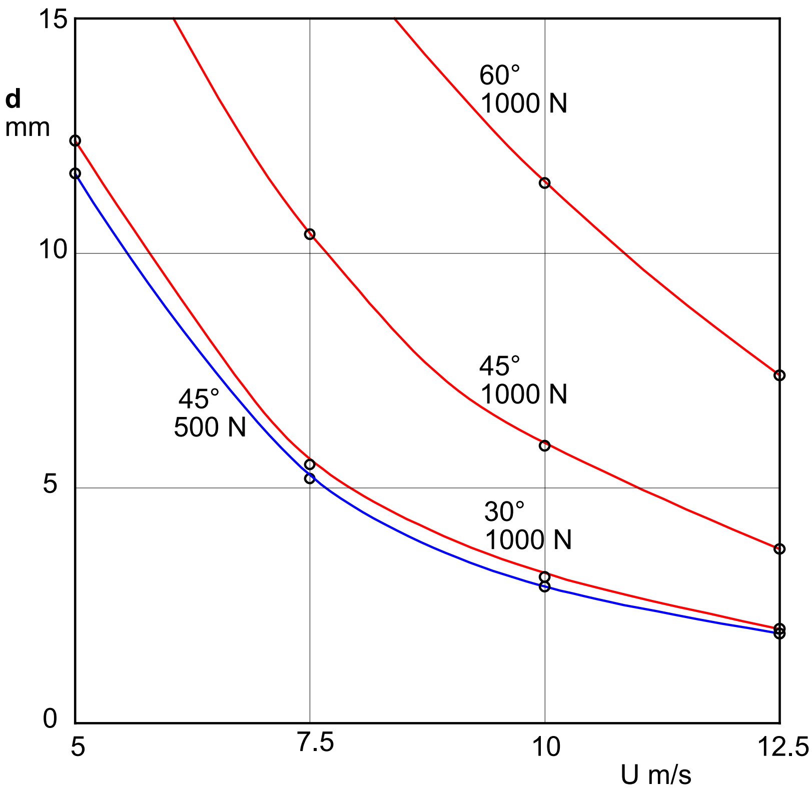

Figure 6-3: Thickness of the skimmed layer for various values of the velocity U .

6.4 TYPICAL OPERATING CONDITIONS

Jet trajectories.

One of the major parameters for the EUROSKIM is the velocity of the carrying boat. We will consider in the following a velocity of 10 m/s (20 kn).

The above results show that an angle of attack of 45° is reasonable. This means that, due to a possible wave effect, the angle of attack may vary between 30 and 60°.

Neglecting again the friction on the board, the vertical component of the velocity in the jet will be of :

$$V_y = U \sin\alpha$$

The theoretical maximum height reached by the jet will be :

$$h_j = \frac{U_y^2}{2g} = \frac{U^2 \sin^2\alpha}{2g}$$

We consider that the receptacle of the mixture will have to be at least at 1 meter above the mean surface of water.

For the three angles considered above, we have calculated the trajectories of the corresponding jets at 10 m/s. They are given on Table 6-2.

The time needed to reach point A is given by :

$$t = \frac{U \sin \alpha}{g}$$

The trajectory total length in the moving frame is given by :

$$L = 2tU\cos\alpha = 2\frac{U^2 \sin \alpha\cos\alpha}{g}$$

U	α °	α rad	h max m	L m
10	30	0.52	1.27	8.83
10	45	0.79	2.55	10.19
10	60	1.05	3.82	8.83

Table 6-2: Trajectories of oil sheet.

Our opinion is that the catchment of jets and the transfer of the emulsion to the ship should made only by gravity. This means that very simple equipment should be used and that a minimum height must be available.

At 10 m/s, the recovery equipment will have his minimum point at 1 meter and this will limit some how the range of angles which can be used under wavy conditions.

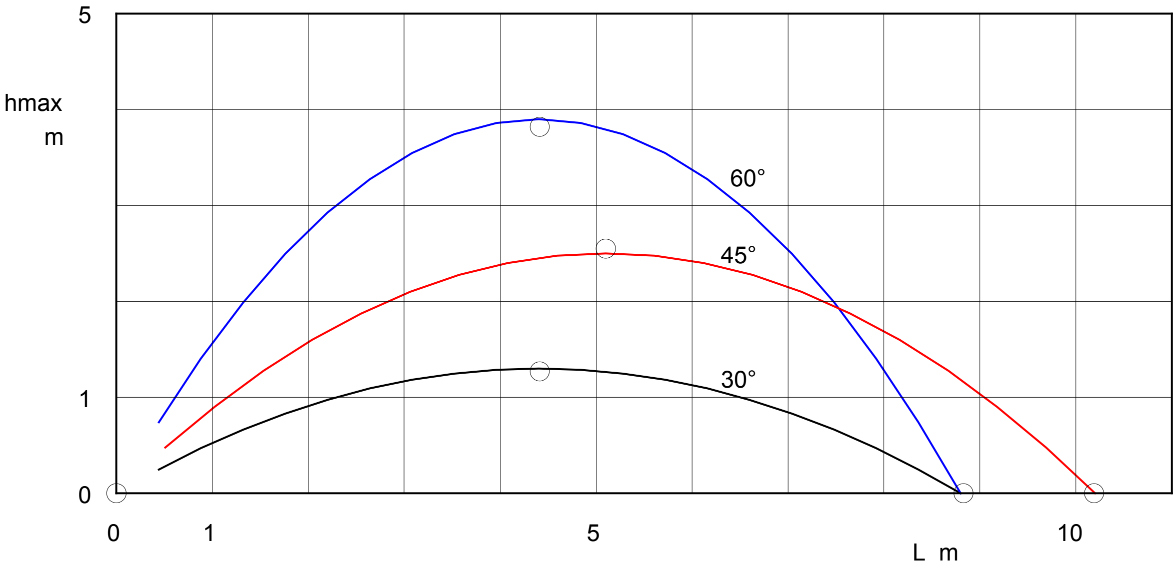

Figure 6-4: Trajectories of oil sheet versus the board angle.

Collection equipment.

Given the trajectories, it is possible to design an equipment to catch the sheets.

Our hypothesis is that the lowest part of the collector should be at one meter above the mean water level.

In order to prevent too much dispersion of the jets at impact, it is possible to install some grids in the catchment area.

A possible solution is given on Figure 6-5.

The two limiting trajectories correspond to skimmer angles of 30° and 60°. The central trajectory correspond to 45°.

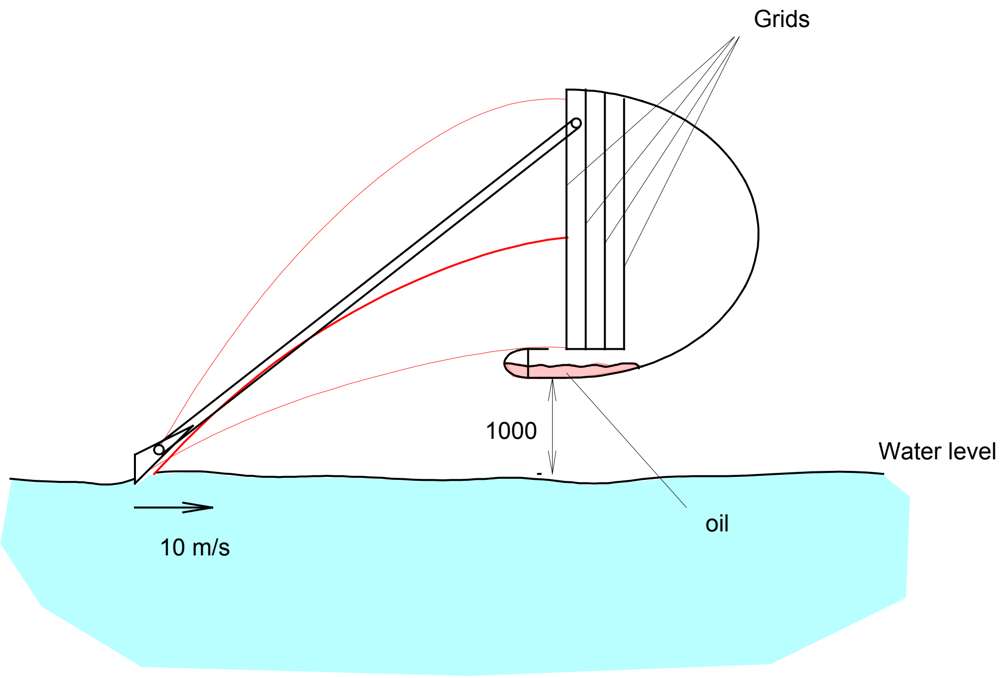

Figure 6-5: A possible catchment system.

The overall dimensions of the system are of some meters. The oil goes though the grids to the elliptical shaped collector. Under impact, the oil covers this shape and flows down along the walls. This very simple system will permit to recover most of the skimmed liquid.

Skimmer installation.

The first solution developed by NEYRTEC was to consider that the height and attitude of the skimming board had to be controlled by actuators to maintain some properties of the jets in a certain range.

Our opinion is slightly different for the following reasons.

We are concerned with lakes where the height of waves and their wavelength are relatively limited. The frequency at which the skimmer should be controlled would lead to a very expensive equipment and to extraordinary high extra mechanical loads.

The system has to be light and put in operation within hours. It is practically difficult to install a hydraulic system and its control equipment in such reduced times.

Finally, the best angle is 45° for all the reasons explained above.

Our solution is based on the use of the weight as the single control equipment. The calculations which have been made above show that a weight of between 500 N and 1000 N is well suited for a 1 m long board.

If we go to a water skier, his weight is of the same order of magnitude and if he crosses waves, evidence show that the water sheet remains regular. In other terms, the stability of the system remains correct even under adverse working conditions. .

The governing parameters in our application are very close to these and it seems that the behaviour of our board should also be similar.

If necessary, it will be possible to add some friction to damp the system and prevent it to quit the water surface, but the principle is to base the regulation on the weight of the skimmer.

A simple way to keep the mean angle of attack at the preferred value of about 45° consists to install the skimmer far from an axis of rotation so that a small variation of altitude will not change the angle of attack.

In the case of a skimmer hold by a 4 m long arm whose extremity is at an altitude of 1.35 m, the angular variation of the board for a variation in altitude of 50 cm is between 53 and 36°.

An interesting feature of this equipment is that the angle at which the sheet leaves the board increases when the depth increases. This means that the jet goes relatively higher when the board is lower. This prevent a too high variation of the sheet altitude when it enters the collector.

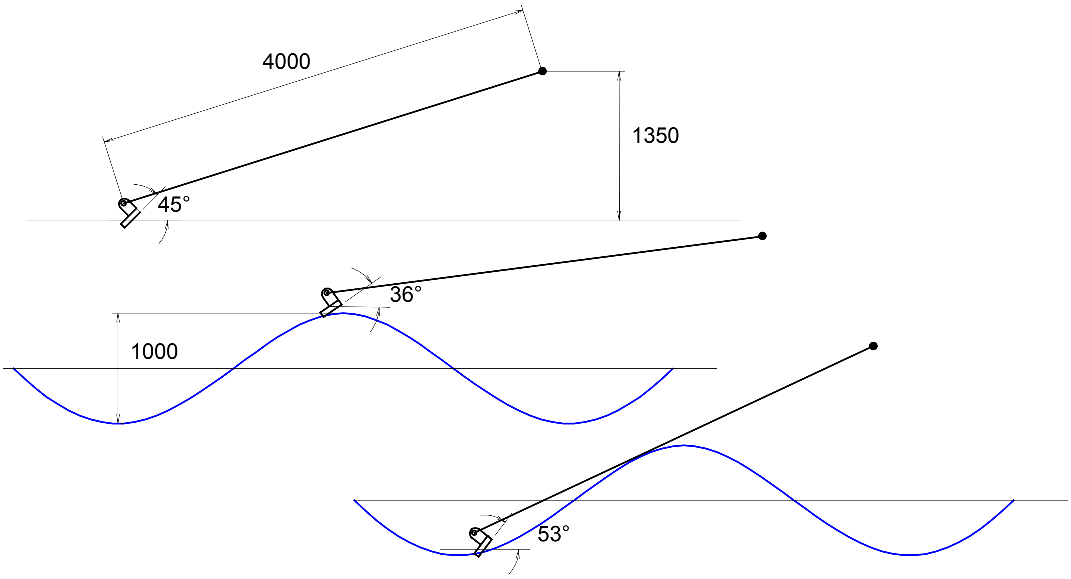

Figure 6-6: Possible installation of the skimmer.

Practically, the skimmer will be attached at the lowest possible altitude. This point will remain at a constant mean altitude. This implies a variation of the altitude of the whole system when the weight and immersion of the boat changes.

Hydraulic circuit.

As we have seen above, typical values of the flow rate are around 60 l/s per meter of skimmer at 10 m/s. The flow will be a mixture of oil, water and air and this makes it very difficult to pump. The only practical solution will be to let the mixture reach the tank by gravity.

In our preferred designed, the width of the skimmer is of 1.5 meter. Practically, the maximum flow rate will be of 200 l/s and this gives a flow rate of 100 l/s on each side of the collecting channel.

The width of this channel will be of 1 meter and its height of 20 cm.

On each side of the channel, the flow will reach a chute and will become torrential. At this point, the local mean velocity in the channel will be equal to the free surface flow critical speed.

If the critical height h_c is of 15 cm, the corresponding critical velocity is given by :

$$U_c = \sqrt{gh_c}$$

And the corresponding critical flow rate will be :

$$q_c = U_c h_c b = b\sqrt{g}h_c^{\frac{3}{2}}$$

With hc=0.15 m and b=1 m, one finds :

$$q_c == 1\sqrt{9.81}\ 0.15^{\frac{3}{2}} = 0.182\ m^3/s$$

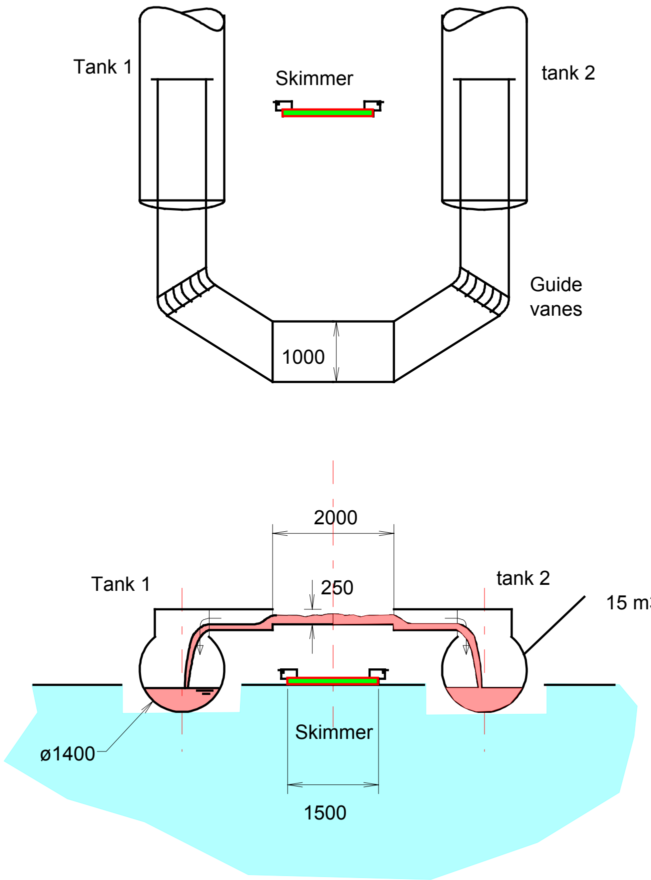

Figure 6-7: Free surface channel to collect the oil-water mixture. Main dimensions.

The circuit designed on Figure 6-7 is well suited to collect the high flow rate involved. The situation corresponds to the very beginning of skimming, when the boat is empty.

Care has to be taken to design the rest of the circuit and any head loss should be avoided. For example, it is recommended to use guide vanes in the elbows and to design a circuit as short as possible. The circuit situated between the collecting channel and the tank will be covered to avoid oil projections. Still, it will work in free surface.

6.5 THE BOAT

General considerations.

The boat must be fast (20 kn) and capable to store a large quantity of liquid. It also has to be very stable in the two planes, longitudinal and lateral. It also has not to settle too much between the two situations where it is empty and full.

The ship's wake must be so that it does not interfere with the skimmer.

Finally, its power should be relatively low compared to its storing capabilities and speed at full load (20 kn).

We think that the best compromise is to use a catamaran boat with a propeller in each hull and a tank per hull. This gives a totally symmetric design.

The wake and skimmer interaction.

Figure 6-8 gives a sketch of the wake formation at the two bows. It is well known that the waves make a 19° angle whatever the design and velocity of the ship.

The recommended solution is to place the skimmer in the non disturbed zone. In order to reduce the superstructure weight, the skimmer should also be placed as near as possible of the centre of the ship.

A best compromise is given where the bow waves are represented and the boat has relatively elegant relative dimensions.

The width of the hulls is of 2 meters and their relative minimum distance of 3 m.

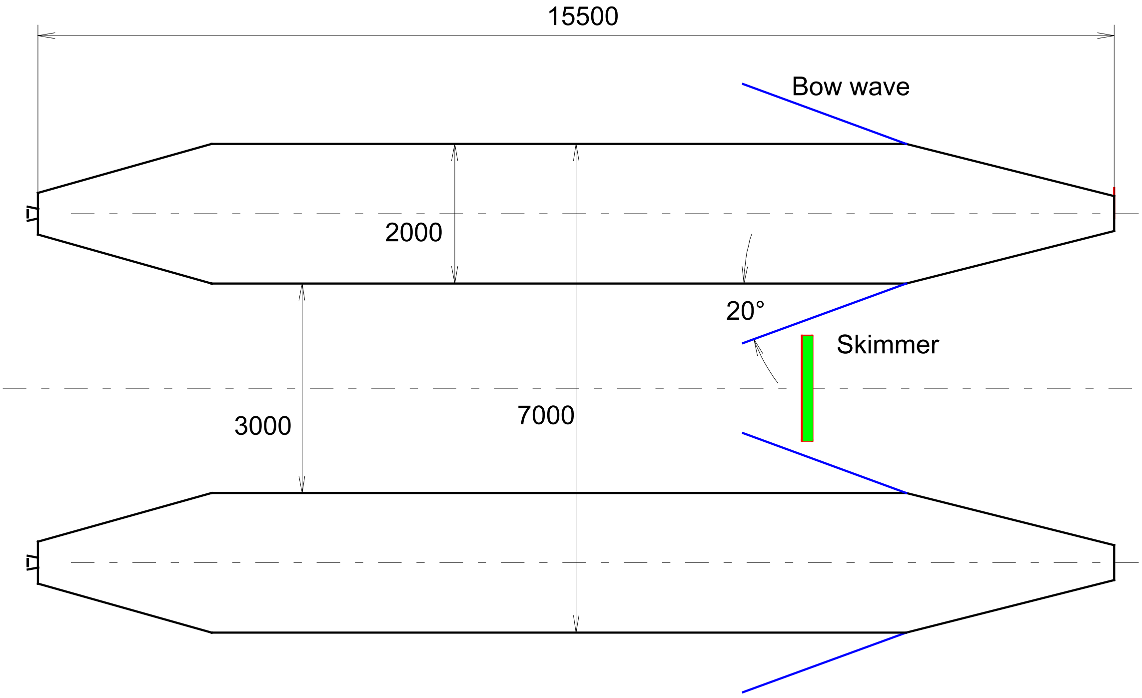

Figure 6-8: Design of the hulls and position of the shimmer relative to the bow. All dimensions are in mm.

The boat has a surface per hull of 27 m^2 and a total surface of 55 m^2.

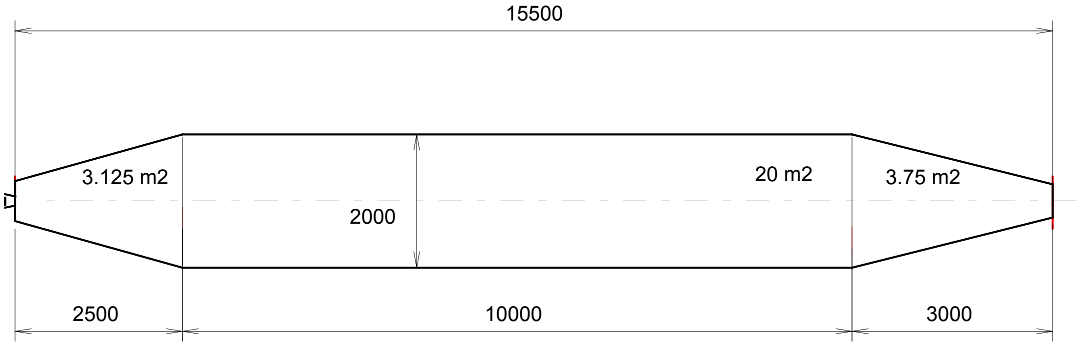

Figure 6-9: Surface of the hull.

One can consider that the maximum sinking of the boat is of about 750 mm. With this dimensions, it would be possible to store 40 tons of mixture. We will see later that this order of magnitude is high enough.

Aerodynamics.

The operation of the skimmer will produce a sheet of water and oil which will rapidly become turbulent. Spray formation is unavoidable and it will be necessary to protect the crew from the mixture. The projections are transported by the relative wind due to the speed of the boat.

To limit the problems as much as possible, a nacelle will be constructed around the jet. The upper part of the nacelle will be aerodynamically shaped and its rear part will reach the central beam of the boat.

Moreover, the nacelle will be linked to the deck and a tunnel will occupy the total length of the ship. This will totally prevent any transport of droplets to the upper part of the bridge.

A sketch of this solution is given on Figure 6-10.

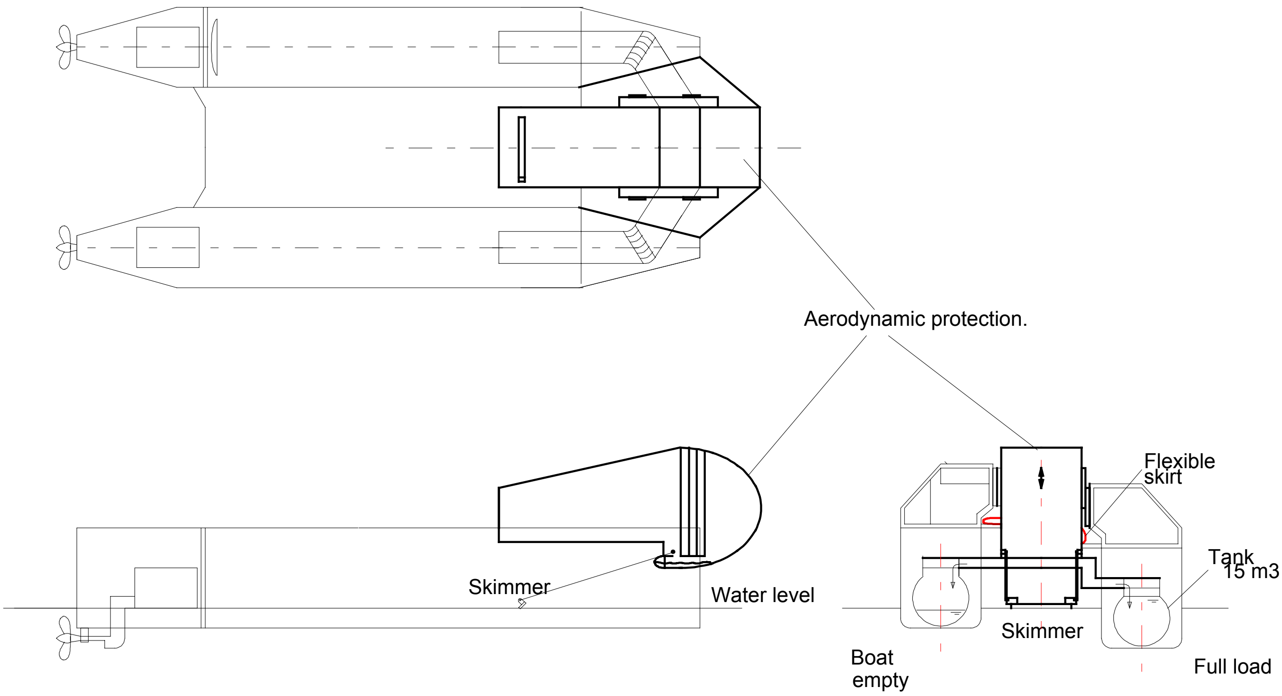

Figure 6-10: Sketch of the aerodynamic protection.

The details of the flexible or gliding parts are nor represented. The important point to note is that the displacement of the "catcher" as a function of load has to be taken into account.

The boat.

The boat is simply constructed from the above considerations. Almost all the dimensions are imposed by the following considerations.

- The optimum average angle of the skimmer is at 45°.
- The apogee of the jet is higher than 1 meter. This fixes the height of the catcher and imposes the location in altitude of the top of the tank. Practically, this gives the size of the largest possible tank.
- The velocity of the boat is imposed by this height. A good order of magnitude is 10 m/s, even though slightly lower velocities could be employed. The velocity must be higher than 8 m/s (16 kn). In that case, the apogee at 45° angle is of 1.5 m.
- Due to aspect ratio criteria for catamarans, the length of the boat is also imposed.
- Finally, the installed power and the type of propeller will be the result of all these parameters

The result is a catamaran boat of 16 meter long and 7 meter wide. Each hull has a maximum width of 2 meter.

A sketch of the system is given on Figure 6-11.

The vessel is of relatively small size. At light conditions, the immersion of the hull is of 500 mm, which correspond to a weight of 25 tons. This may be slightly changed depending on the power of the propulsion and the ancillary equipment. A relatively high tonnage is necessary because the boat has to be very stiff.

One of the important points is that the catamaran can be easily dismantled and transported by truck on a lake site.

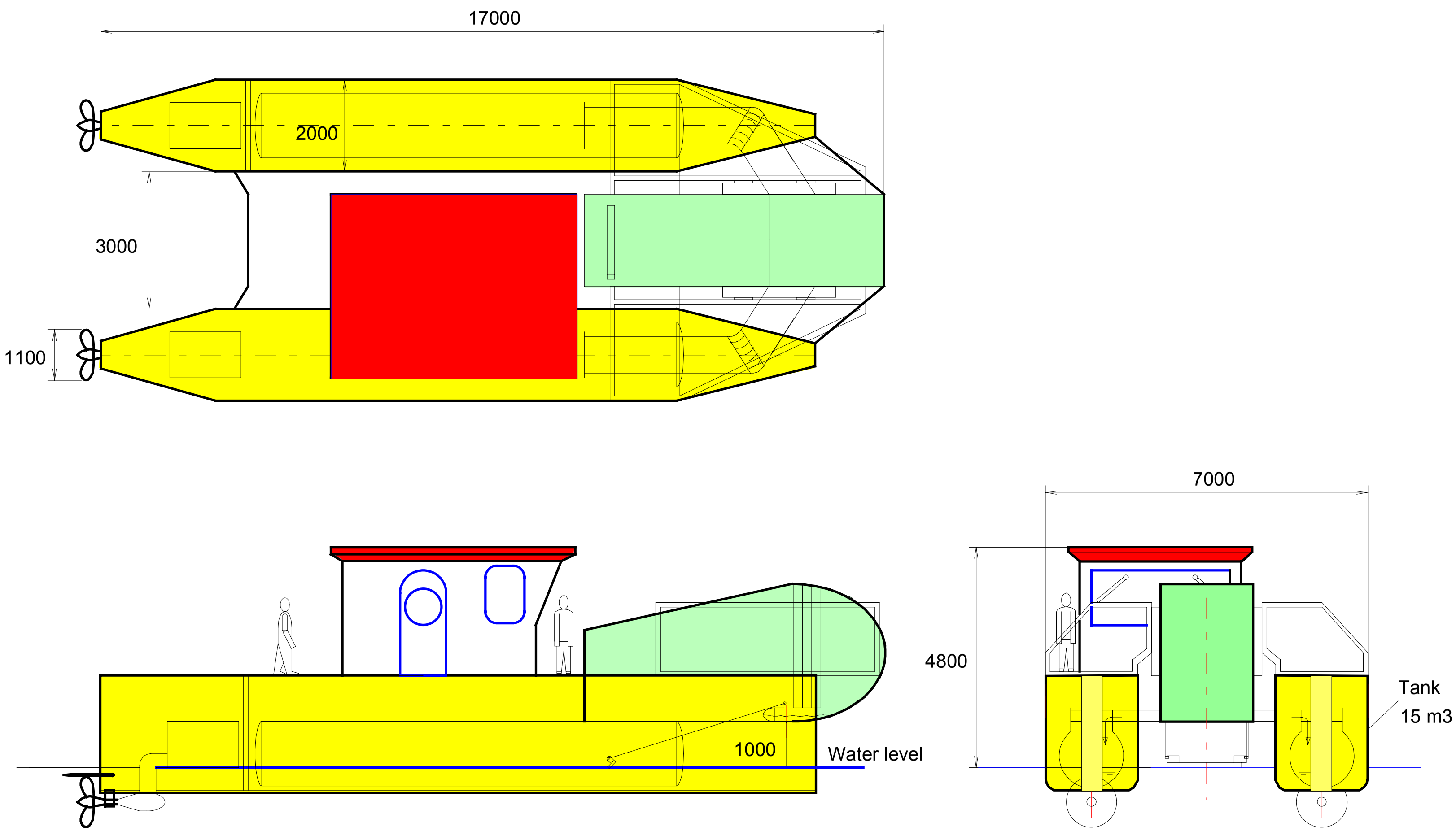

Figure 6-11: Sketch of the boat

The tanks.

The two tanks must be installed below the oil catcher. The only way to pour the mixture is by gravity.

One of the problems is to prevent too much fluid movement in the tanks which would change the incidence of the ship and would modify the quality of the skimming procedure.

The classical solution is to divide the tank in small individual compartments.

At this stage of the project, each tank is 9 meter long and 1.4 meter in diameter. A good compromise could be to divide the tank in 5 secondary tanks of 1.8 m long.

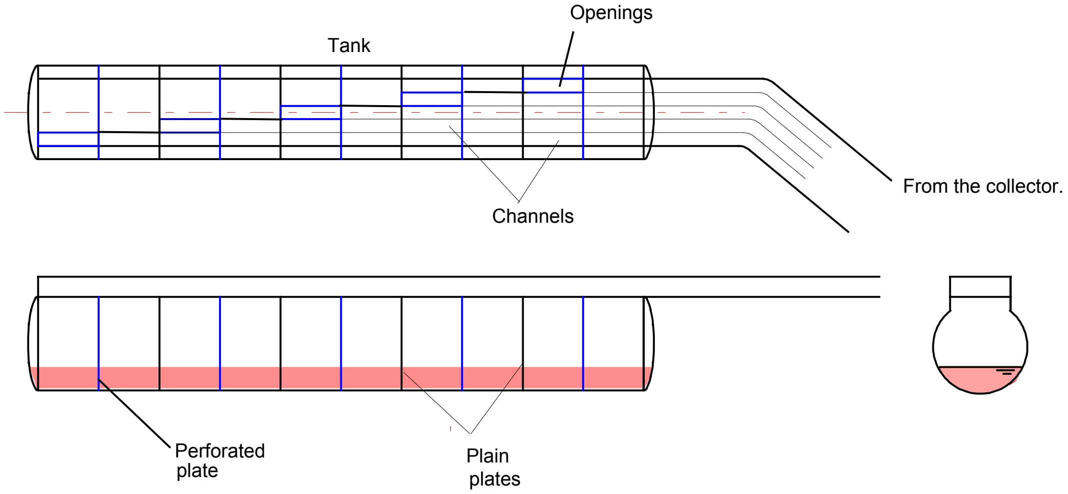

Figure 6-12: Dividing channels for flow repartition.

A simple solution which does not need any extra automatic control may consist in dividing the main flow coming from the sheet collector in 5 channels. Each of these channels could be linked to a large opening at the top of each tank. Even though this solution is not perfect, it will certainly permit to feed all the secondary tanks up to a certain level. When one of the tanks is full, the boat will be immersed and the natural available head will be higher. It is most probable that this will help to full up all the other secondary tanks despite the limitation of the passages.

For the skimmer under project which should remain very simple and easy to use, it would be too much complex to develop a specific regulation to get the same level in all the secondary tanks.

The effect of a disequilibrium between the secondary tanks can be simply evaluated by calculation. It has been supposed that the maximum possible disequilibrium consisted in one tank full and the opposite tank empty. This is illustrated on Figure 6-13.

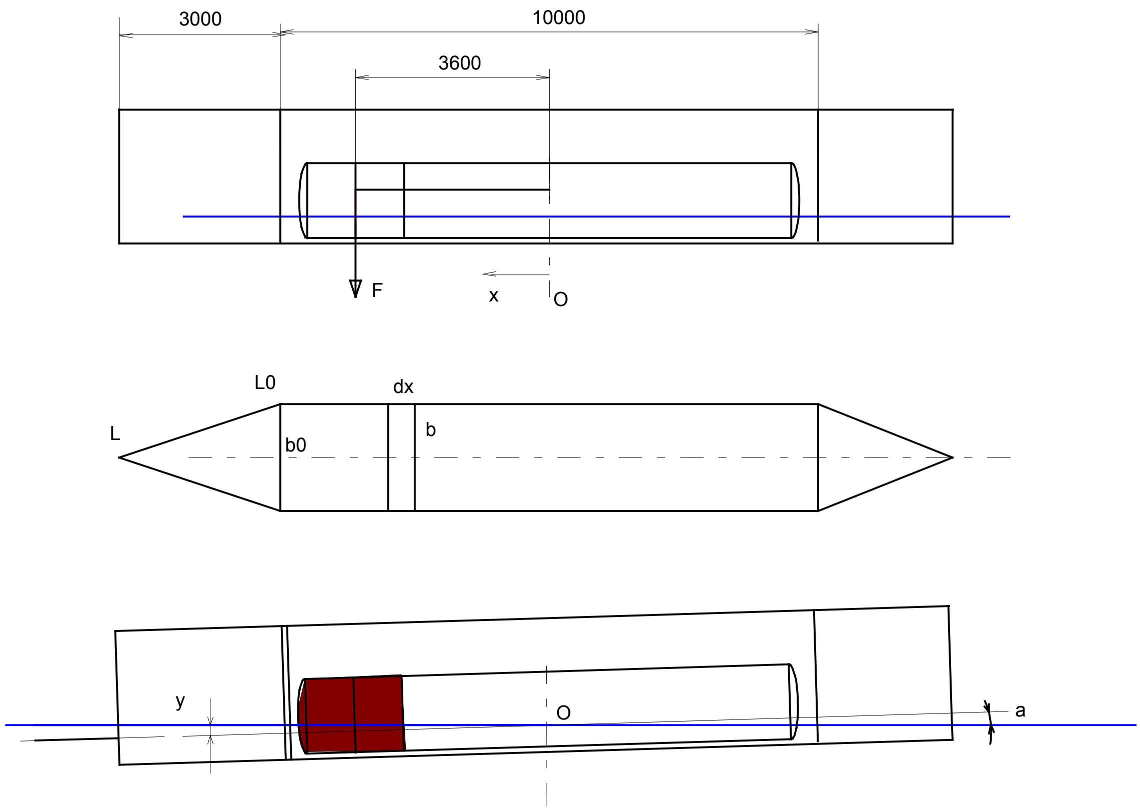

Figure 6-13: Calculation of the incidence angle α due to disequilibria between the extreme secondary tanks.

The moment due to the weight difference can be written :

$$M_0 = F\,l$$

This moment must be compensated by the inclination of the hull. The corresponding moment due to the buoyancy difference can be written :

$$M_1 = 2\int_0^L xybg\rho dxl$$

with :

$$y = x\ \mathrm{tg}\alpha$$

This gives :

$$M_1 = 2\mathrm{tg}\alpha\int_0^L x^2 bg\rho dx$$

The hull is made of two parts :

In part 1, for $0<x<L_0$ b is constant equal to b_0.

In part 2, b is a triangle and its equation is given by :

$$b = b_0 \frac{L - x}{L - L_0}$$

The calculation of the moment M_1 gives :

$$M_1 = 2tg\alpha \int_0^{L_0} x^2 b_0 g\rho dx + 2tg\alpha \int_{L_0}^{L} x^2 b_0 \frac{L - x}{L - L_0} g\rho dx$$

or :

$$M_1 = 2tg\alpha \int_0^{L_0} x^2 b_0 g\rho dx + 2tg\alpha \int_{L_0}^{L} x^2 \frac{Lb_0}{L - L_0} g\rho dx - 2tg\alpha \int_{L_0}^{L} x^3 \frac{b_0}{L - L_0} g\rho dx$$

Integration of this equation gives :

$$M_1 = 2b_0 tg\alpha g\rho \left[\frac{L_0^3}{3} + \left(\frac{L^4 - L_0^4}{3(L - L_0)} \right) - \left(\frac{L^4 - L_0^4}{4(L - L_0)} \right) \right]$$

$$M_1 = 2b_0 tg\alpha g\rho \left[\frac{L_0^3}{3} + \frac{(L - L_0)(L^2 - L_0^2)}{12} \right]$$

Equating M_0 and M_1 enables to calculate the angle α :

$$F\,l = 2b_0 tg\alpha g\rho \left[\frac{L_0^3}{3} + \frac{(L - L_0)(L^2 - L_0^2)}{12} \right]$$

One finds :

L_0=5 m
L=8 m
b_0=2 m
l=3.6 m
F=30 000 N

and : $$tg\alpha = \frac{F\,l}{2b_0 g\rho \left[\frac{L_0^3}{3} + \frac{(L - L_0)(L^2 - L_0^2)}{12} \right]}$$

One finds :

$$\mathrm{tg}\alpha = 0.052$$

Or α=3°

This angle can be considered as a maximum It will not change the behaviour of the skimmer.

The variable weight skimmer.

The thickness of the skimmed layer is proportional to its weight or more generally to the force which is exerted by the water.

As the skimmer is installed at the end of a rotating arm, it is sufficient to apply a moment with a weight to obtain the same result.

It has been shown that the weight to apply at 10 m/s and a thickness δ of 6 mm a weight of 1000 N (100 kg) for a width of 1 meter.

The project is based on a 1.5 m width for the board. The typical weight to apply can be of 3000 N to remove a layer 1 cm thick.

We will fix the maximum applied force at 1 "ton" (10 000 N) corresponding to a 3 cm layer.

The consequence is that the total weight should be varied between 1000 N and 10 000 N.

A simple solution is to prepare a set of calibrated masses which can be installed and secured on the arms.

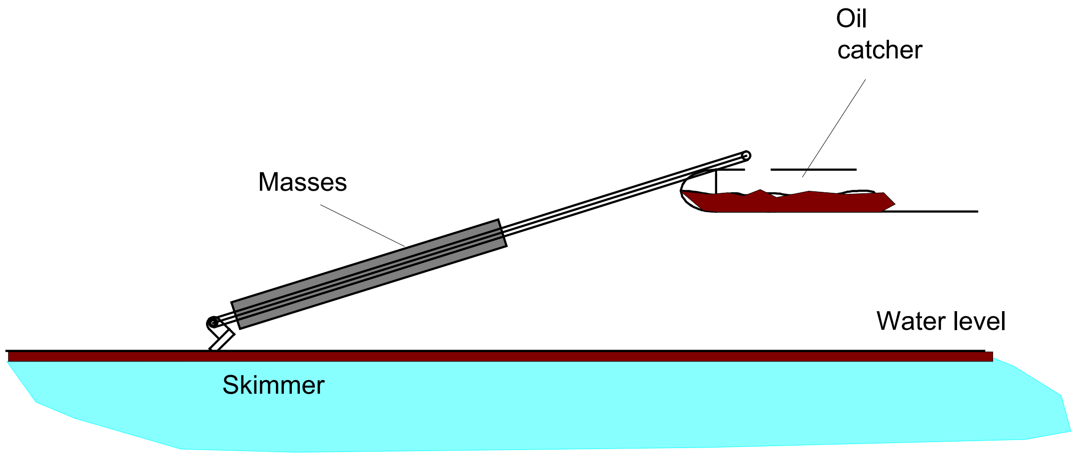

Figure 6-14: Installation of masses on the skimmer.

The simplest way to fix the arms may be to install them with an ancillary boat passing below the main catamaran vessel. The elementary mass should be light enough to be easily displaced by one or two men.

Propulsion.

The boat is relatively fast and needs high power for propulsion.

To give an order of magnitude, it is necessary to calculate the drag of each hull. We consider a weak interaction between the two hulls.

The resistance of a ship in calm water is considered to be the sum of friction and components due to the waves produced by the vessel.

This drag force is generally presented as follows :

$$F_D = \frac{1}{2}\rho U^2 \frac{8\pi\nabla^{\frac{2}{3}}}{1000}\left(C_v + C_w\right)$$

where ∇ is the volume displacement of the ship

$$\nabla = \frac{M}{\rho}$$

C_V is the viscous drag coefficient
C_W is the wave drag coefficient.

The viscous drag coefficient is given by :

$$C_v = \frac{\chi}{\left[\log\frac{UL_S}{\nu} - 2\right]^2}$$

L_S is the total length of the ship.

χ depends on the block coefficient d which is given by :

$$\delta = \frac{\nabla}{L_S BT}$$

B is the maximum width of the ship and T the draft at the middle of the ship.

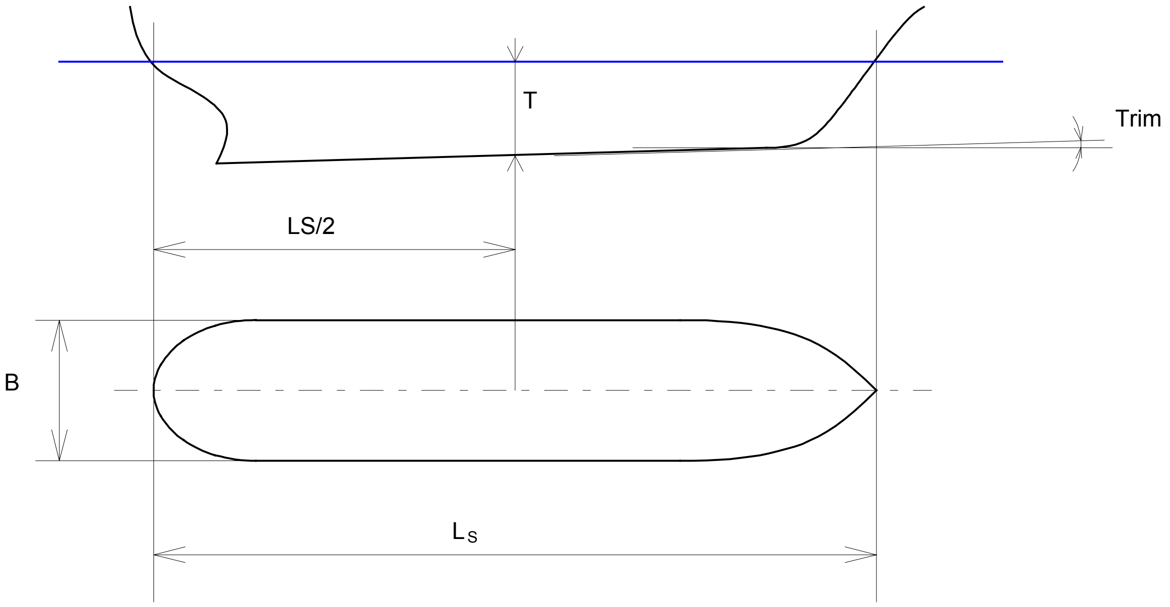

Figure 6-15: Notations for a ship.

One defines the dimensionless wetted surface S_w :

$$S_w = \frac{S}{\nabla^{\frac{2}{3}}}$$

We have calculated these parameters for our vessel at full payload and we find for each hull :

M kg	∇ m^3	L_S m	T m	B m	□	S m^2	S_w
25 000	26	16	1	2	0.8125	58.65	6.68

The results are given on curves[3] not drawn here.

χ is a function of δ and S_w.

It is found from a set of experimental curves that

χ=21

And the viscous drag coefficient is given by :

[3] R.D. Blevins. Applied fluid Dynamics Handbook. Krieger Publishing Company. Malabar Florida 1992.

$$C_v = \frac{\chi}{\left[\log\frac{UL_S}{\nu} - 2\right]^2} = \frac{21}{\left[\log\frac{10\,16}{10^{-6}} - 2\right]^2} = 0.546$$

The part of resistance F_v due to viscous drag is equal to :

$$F_v = \frac{1}{2}\rho U^2 \frac{8\pi\nabla^{\frac{2}{3}}}{1000}(C_v) = 6021\ \text{N}$$

The second part of the drag is the drag due to the waves generated by the ship. The dimensionless wave coefficient is a function of Froude Number. Practically, for a given ship, it grows as the fourth power of velocity.

This drag coefficient can be written as follows :

$$C_w = 175.6\frac{Q}{M^3}$$

with the dimensionless coefficient M, which is a kind of aspect ratio, given by :

$$M = \frac{L}{\nabla^{\frac{1}{3}}}$$

The wave coefficient Q is calculated from experimental curves. It depends on a velocity parameter, K and of the block coefficient δ.

$$K = \frac{U}{\left(\frac{g\nabla^{\frac{1}{3}}}{4\pi}\right)^{\frac{1}{2}}}$$

K is a Froude Number based on the cubic root of the hull volume.

The corresponding results are given on the following array which concerns only one hull.

∇ m^3	δ	M	K
26	0.8125	5.4	6.57

Table 6-3: Results obtained with the first project.

The analysis of the existing correlation show that this design is not satisfactory and that some changes have to be given to the project to reduce the wave resistance.

To do so, it is necessary to increase the length of the ship or to lower the block coefficient.

This shows that hydrodynamic aspects are an important part of the design.

Standard design.

Commercial Catamarans already exist which have performances and dimensions of the same order of magnitude

The example of the Blubay Motor cat 100 is given below.

LOA	29.4 m / 98'
LWL	27.1 m / 90.3'
BEAM	11.1 m / 37'
DRAFT	1.02 m. / 3.4'
DISPLACEMENT	55 tons half loaded
CONSTRUCTION	GRP / Composite
CLASSIFICATION	D.N.V.
MAIN ENGINES	2 x 850 HP up to 2 x 1450 HP
MAXIMUM SPEED	+ 28 knots
RANGE at 18 knots	1,000 - 2,000 Nm
GENERATORS	2 x 25 KVA
GUESTS CABINS	4 or 5 double
CAPTAIN / CREW'S CABINS	2 double
FUEL CAPACITY	5,000 l. / 1320 US gal.
FRESH WATER CAPACITY	2,000 l / 528 US gal.

AIR CONDITIONING	150,000 BTU
WATER MAKERS	2 x 350 l/h
TENDER	1 x 5.50 m.
NAVAL ARCHITECT	BLUBAY YACHTShttp://www.blubay.com/english/bb100mc.htm

Table 6-4:

Smaller models exists like the Motorcat 80 the length of which is of 22.51 meters. The minimum power is of 2x350 HP. The maximum velocity with 2x850 HP reaches over 28 knots.

"Après deux années de développement, le bureau Gilles OLLIER & ASSOCIES a publié les plans d'un nouveau concept de catamarans à moteur, l'Ocean Twins 60 et 75. Des coques à déplacement léger - suffisamment espacées - ont été choisies pour combiner à la fois performance, passage dans les vagues, confort en mer, manœuvrabilité dans les ports et bonne autonomie de carburant avec des moteurs de taille raisonnable."

Les plans

Caractéristiques	**Multiplast 60**	**Multiplast 75**
Longueur hors tout	18,28 m	23,12 m
Largeur	8,65 m	10,1 m
Tirant d'eau	1,30 m	1,35 m
Déplacement	18 t	26 t
Motorisation	2 x 430 cv	2 x 660 cv
Matériaux de construction	GRP - epoxy - mousse PVC - sandwich	

Table 6-5: Contacts have been taken with the Multiplast shipyards in France.

7 OPERATIONAL PROCEDURE

7.1 FOREWORD

The Euroskim must be emptied after each run. This means that either shore installations or tankers have to be used to make this operation.

The typical figures are as follows:

- Capacity of the Euroskim : 25 m^3.
- Typical flow rate skimmed : 100 l/s
- Typical duration of a run : 250 s
- Length of a run : 2.5 km.
- Surface skimmed in one run : 3750 m^2.
- Total weight at full load : 40 Tons.

The problems to solve are the following :

- How to suck the water from the Euroskim to the tank ?
- How to separate the water and oil contained in the mixture?

7.2 TRANSFER OF THE MIXTURE

There are two possible ways to transfer the mixture from the boat to the tanks. The first is to use low pressure tanks and the second to use pumps on the boat.

The transfer of mixture should be very fast. For example the complete transfer including docking should last less than 5 minutes. This means that the transfer should last 3 minutes.

As there are about 2 times 12.5 m^3 to transfer, each pump should have a capacity of 100 l/s. One pump would be used to pump the mixture of one side of the boat.

As the tank is divided in 5 secondary tank in the project, these tanks should be linked by a manifold equipped with automatic valves between two compartments.

The sketch of this arrangement is given on Figure 7-1.

The pump could be a KSB ETANORM 125 200 / 208 160. The power of the electric motor could be of 55 kW. The typical head is of 35 meter at 2900 rpm and 100 l/s.

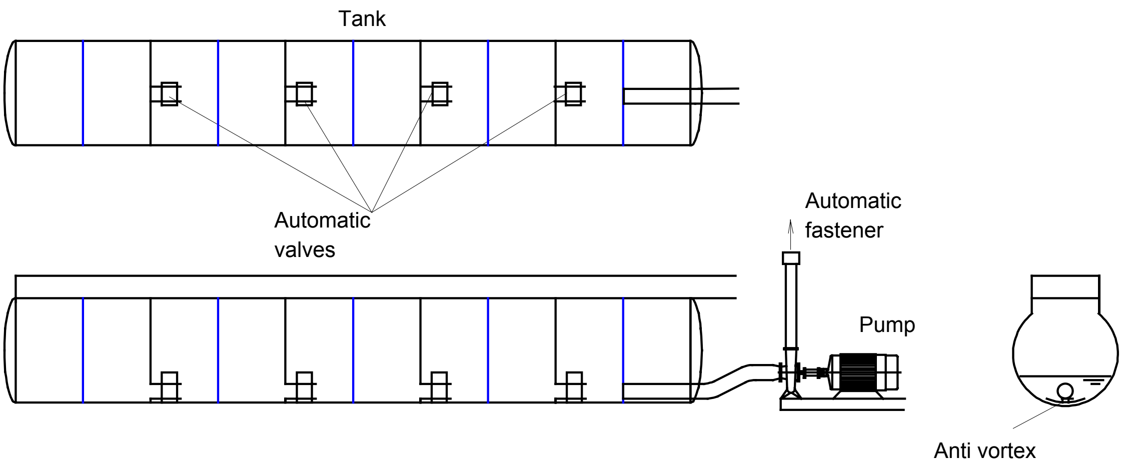

Figure 7-1: Installation of pumps on the tanks.

The secondary tanks should be linked by tubes equipped with automatic valves to permit the transfer of the liquid from one tank to the other.

Care should be taken at the water intake to avoid the formation of vortices. Typical solutions consist to install plates and fins.

It should be noted that the diameter of tubing should be of 200 mm. An automatic fastener has to be installed between the skimming boat and the flexible hose which transports the mixture to the tank or the tanker.

7.3 OIL-WATER SEPARATION.

General comments.

The mixture pumped will contain oil and water and typically, the volume of water will be higher than the volume of oil, say 2 or 3 times. This makes it necessary to use oil and water separators.

In the case of a tank onshore, the simplest solution may be to wait or to use a compact gravity separator. Such separators exist on market. Their typical residence time is of 100 s.

Some designs such as our "Optipack" permit to reduce this time at 30 s. This is due to the size reduction of inlets and outlets and to the use of fine mesh honeycombs. A sketch of Optipack is given on
Figure 7-2.

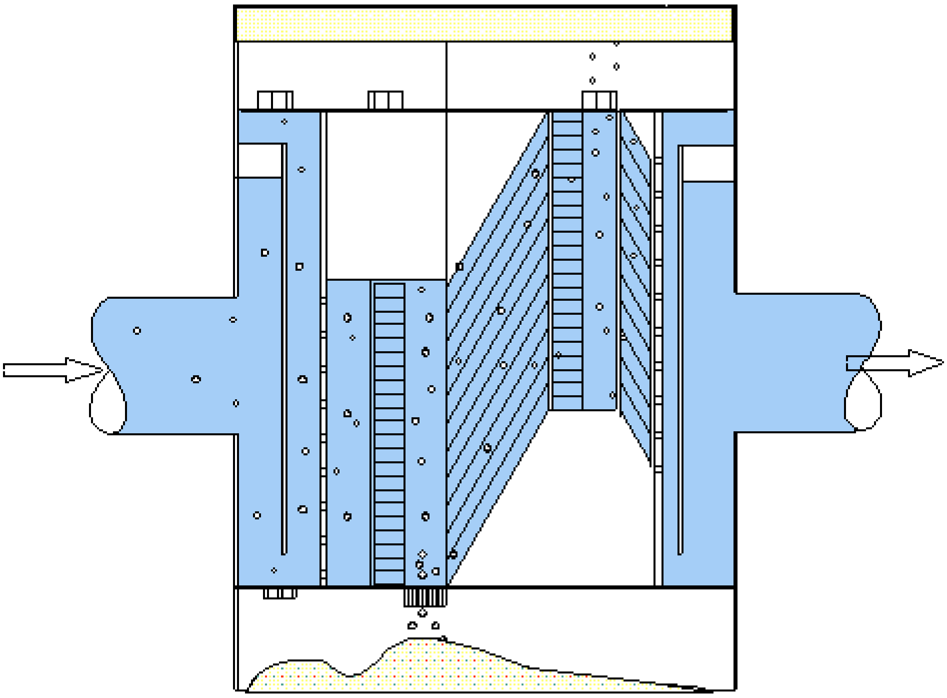

Figure 7-2: OPTIPAC compact multiphase gravity separator.

In the case of a tanker, it may be necessary to use a high speed separator. Practically, these separators can be high capacity cyclones.

Conventional cyclones.

The cyclone technology is well known for solid-liquid and fluid-gas separation.

Cyclones can also be used to separate oil and water. This technology has been actively developed about 20 years ago for liquid-liquid separation especially as secondary treatment. This means that the cyclones have first been used to take rid of concentrations of some percent of oil in water.

More recently, cyclones are able to treat low water cut emulsions, the water cut being defined as the relative part of water in the total volume of emulsion.

$$WC = \frac{V_w}{V_0 + W_w}$$

The development of equipment to remove water from oil downhole is one of the reason of these recent developments.

The conventional designs of cyclones are based on tempered cyclone bodies, tangential inlets and a flow of oil at overflow and of water at underflow. To reject pure water, it is necessary to install two sets of cyclones in series. These equipments are developed by companies like Kvaerner in Norway or Baker Hughes in the United States.

The typical flow rate per cyclone per first stage element is of 2 l/s. This means that about 50 cyclones should be installed at the first stage and about 30 cyclones as a second stage.

The OPTISEP.

The OPTISEP concept has been developed by Ylec Consultants in a joint development program sponsored by TOTAL and the French "Fond de Soutien aux Hydrocarbures".

It is well known that one of the main limitations of static cyclones is the friction of water on the walls. This induces a loss of moment of momentum and the production of turbulence in the separator. Moreover, in conventional cyclones, the two exits are on each side of the separator which is nor a good solution for a separator.

For these reasons, we have designed a high speed single stage separator able to process up to 36 l/s. It can work at any Water-Cut between 50% and 100%. The tests done in 2000 and 2001 gave very encouraging results.

A sketch of the system and its main dimensions are given on Figure 7-3.

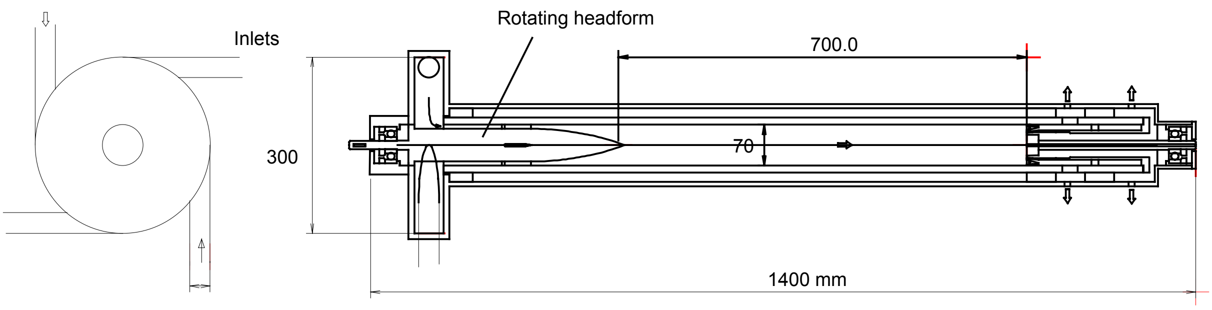

Figure 7-3: OPTISEP with a central headform and precyclone. The separator diameter is of 70 mm at 3600 rpm.

This Optisep is able to process up to 12 l/s of mixture at any water-Cut. Scaling laws show that an OPTISEP of 100 mm in diameter is able to process up to 36 l/s.

In principle, an OPTISEP of 150 mm could treat 100 l/s, but a better solution in terms of head losses would be to limit the diameter at 100 mm and to install three separators.

Ylec Consultants also develops static separators at high flow rates, the STATISEP which can be used to separate oil and water in the same range of water-cuts and flow rates.

8 NOTATIONS

b m	Width.
B m	Width of a ship.
Cv	Coefficient of viscous friction.
Cw	Drag Coefficient due to waves.
e m	Thickness of the oil layer.
e_0 m	Initial thickness of the oil layer.
F N	Force.
F_D N	Drag force.
F_x N	Projection of the force in the x direction.
F_y N	Projection of the force in the y direction.
g m/s^2	Gravity acceleration.
h m	Height.
h_j m	Apogee of the jet.
h_c m	Critical height.
K	Froude number.
l m	Length.
L m	Width of the Cyclonet.
L m	Half length of the boat.
L_S m	Total length of the boat.
M m.N	Moment.
M kg	Mass.
M	Aspect ratio.
n	Exponent.
N rpm	Rotation velocity.
q m^3/s	Flow rate.
Q	Coefficient.
r m	Radius.
r_0 m	External radius.
r_2 m	Radius at water outlet.

S m^2 Surface.

S m^2 Wetted surface.

S_w Non dimensional wetted surface.

t s Time.

T m Draft.

U m/s Velocity.

U_c m/s Critical velocity.

U_T m/s Tangential velocity.

U_{T0} m/s Tangential velocity at the entrance.

x m Abscissa.

y m Vertical co-ordinate.

∇ m^3 Volume

α Coefficient.

α ° Angle.

χ Drag parameter.

δ m Thickness of the skimmed layer.

γ_c m/s_2 Centrifugal acceleration.

n m^2/s Kinematic viscosity.

ρ kg/m^3 Specific mass.