ILASS 2008
Sep. 8-10, 2008, Como Lake, Italy

Paper ID ILASS08-13-17

STUDY OF SPRAY TECNOLOGY FOR LUBRICATION

A.Amoresano, F.Langella, V.Niola,

Department of Mechanical Engineering Naples University "Federico II", Via Claudio 21

ABSTRACT

In this paper the forced lubrication by spray is analysed. The study is carried out by use optical facility like CCD camera to acquire speed images of the impact phenomenon. The aim of this research programme is to study by experimental approach how the spray technology can be use in to a gear box lubrication or in general in a kinematic pair .The results are quantified by frames and diagrams that explain the mainly lines of the work. The correct operation of gear transmission, and the consequent good efficiency of transmission, depends on the formation of a lubricating layer between two surfaces. It the perfect lubrication assures. The layer reduce not only the sliding between the surfaces but also the superficial stress due to dynamical conditions . Analyzing the standard and a forced lubrication process for a kinematic pair using the second one it is possible to drain large amounts of heat from friction.

The measurements of the size and velocity of distribution of small particles is a need in many branches of engineering science. Special difficulties arise in the application of the methods to measure sizes and velocity of drop in a spray; these difficulties include: *a*) the very large number of drops, *b*) the high and variable velocity of the droplets, *c*) the wide range of drop sizes, and *d*) the changes in drop size with time due to the breakup and coalescence. In this paper the photographic methods has been chosen for studying the behavior of the lubricant droplet after the impact on hot surface.

1 INTRODUCTION

During last years, the development which was reached by propellers as services and efficiencies made the need evident to adjust for instance lubrication systems. Especially for kinematics couples Which were submitted to high friction conditions, it is necessary to look for new solutions which allow the improvement of lubrication process[5], increasing transmission efficiencies and useful life of transmission. Because of this, it's important to study the usefulness in the tribologic field of atomization technologies. As they were shed in many fields from injection system of engine motors with inner combustion to gas(fuel) whirl, to conditioning system of environments.

The target was to develop a new system of lubrication where one or more injectors atomize lubricant which was previously filtered, sending it in very little drops on the surface of transmission elements. A technology like this, would allow to solve all those errors which happen in traditional lubrication systems. Lubrication is no more due to messy movement of the oil inside the carter which is caused by 'shaking', but to nozzles action, which address on kinematics couples oil quantity (which is needed) with determined trajectory and speeds; in this manner it's possible to get the certainty that between the contact surfaces there is always the quantity of lubricant which was given on project parts and there is the possibility to proportion lubrication regime. Because of a system working, it's necessary that the drops of the spray jet, once the kinematics surfaces are reached, could share coalesce) in a very short time to form then an uninterrupted film of lubricating. The aim of his job is to characterize with experiments drop phenomenon and 'sharing' for a lubricating oil in order to achieve useful data for a next project of geometrical and fluid-dynamic parameters of the spray. Some base concepts are shown because of physical phenomenon's which happen on spray lubrication process as atomization, drop-surfaces impact and 'sharing'.

2 SPRAY LUBRICATION

This system shows in the essential lines a circuit where oil which is taken away from a small basin by means of a pump, passes through a filtering system and it reaches with a certain pressure the injectors; these one can get misty and take the lubricant on coupling the surfaces going then on a crop small basin.

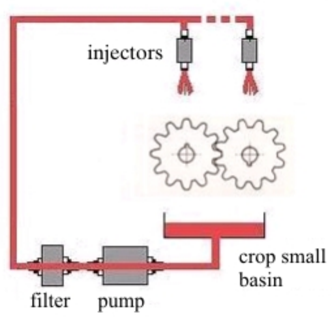

Fig. 1. Layout of spray lubrication

This technology, try to solve all inconvenient that we find in the traditional lubricator system. In the lubrication spray system the oil when it arrives in surface, came back from a process of filtering, without impurity. Another advantage of this solution is the lack of speed. Since the wheels are not dipped in the tank, it hasn't submit to pasty endurance.

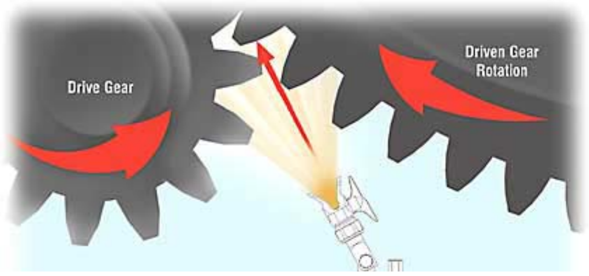

Fig. 2 Gear box lubricated by spray

Another advantage of this solution is the speed working without lack. As the wheels aren't dipped into the basin they are not submitted to a pasty endurance, so at one hand there aren't problem linked at the reduction of performance, at the other hand there isn't any problem concerning oil emulsioning and unwanted heat production.

Apparently a plant so described seems to be easy, to realize actually it shows a lot of problems linked above all to the optimization of lubricant injector settings. a first problem is linked to the choice of the number the type and position of injectors, then it is necessary to tweak fluid-dynamic settings. of the spray jet, such as the distribution of the diameters of the drops, the geometry of the above mentioned jet, the quantity of lubricator, the frequency of the injector, the speed of drops impact.

The optimization of all these factors cannot put aside from a experimental study. Also if the spray represents a consolidate technology and it is supported by a good theory and experimental base, the results found in literature supply a partial help to the studies of our interest. While in the common spray applications the main purpose is to obtain a nuke force, in order to accelerate chemical/physical processes that produce in the interface between two different phases, in the lubrication spray the primary purpose is to induce the drops of the atomized jet, once reached the surface to lubricate,and to coalesce as soon as possible creating a perpetual process. Noticeably the lubrication spray process is the result of the following three phases:

- Lubricant atomization
- interaction of the jet with the surface (impact drop-surface)
- interaction between drops of the jet on the surface (coalescence)

A special attention is set for the last two points, because the atomization process already has a large bibliography.

The study of phenomena of impact and coalescence is experimentally analyzed in this work.

3 EXPERIMENTAL

The experimental activity has been guided near DIME laboratories, about the study of the phenomena of impact drop and coalescence. Through this system it is tried to simulate the conditions that it came throw inside of a change of type automobile. As already introduced in the previous chapter, the proper lubricator is due to a continues lubricant process between the surfaces in a relative motion; the purpose of this research is checking if at the temperature of change functioning the conditions exist for obtaining a complete coalescence of the lubricant drops injected under spray form. The coalescence phenomena of dynamic speed has asked for observation of phenomenon, the use of a camera at a high speed of data capture.

The experimental apparatus can be divided in the following unit:

- Heated plate that simulates the surface of job of a change and system of regulation temperature
- Falling-drops system
- Illumination plate system
- Acquisition temperature plate system
- Acquisition imagines system

You brings following the scheme of the bench tries.

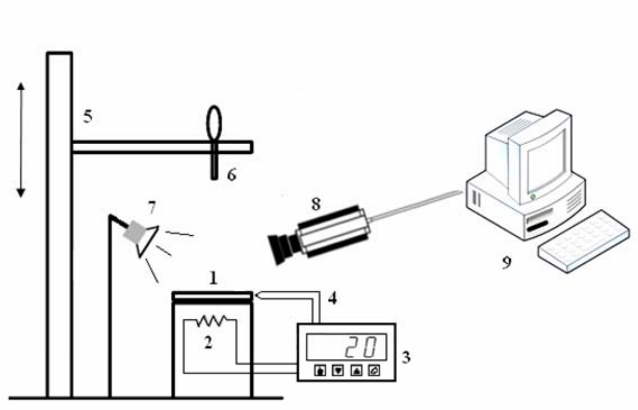

Fig.3 Setup facility

3.1 Drop impact study for a fluid highly viscous

To optimize the process of lubrication spray means to optimize every single step above mentioned, each of them characterized by their own phenomenology. During the experiment phase, we started studying the impact of a single drop in order to comprehend how a single drop react to an expansion on a surface with variable temperatures after that, we proceeded analyzing the coalescence of two drops.

Then we show the experimental proves related to the first step, that is the drop-surface impact. Experimental proves have been managed using a lubricant for transmissions EP type, whose characteristics are reported below:

Mark: **EUROLUBE**
Type: **eplus 5**
SAE **80W/90**
API **GL5**

3.2 Study of the times of drop expansion

By fast imaging we have studied the influence of parameters like temperature of surface and the speed of impact forward the expansion of the drop. We have in particularly three test each one with a full value of the height of the crash of drop, to register also the time of enlargement for three different value, of plate temperature, the choice of value of speed impact has been banded at three different height between plate and system of drops.

The height has been chosen to check the sensibility of growth of the drop after the impact. The value has been 15 cm, 40 cm e 70 cm, they correspond at $v = \sqrt{2gh}$, value of speed impact severally 1.7 m/s, 2.8 m/s, 3.7 m/s.

For such value of the droplet velocity the values of and from the knowledge of the characteristics of the fluid the following values of the Weber number are carried out (ρ = 877,7 kg/m^3, σ = 26 mN/m, D_{med} = 3 mm)

- We = 301
- We = 804
- We = 1407

For these weber' s number the behavior of the droplets didn't change. The impact of the oil droplet on the surface was without rebound and splashing. The droplet after the impact increases its area

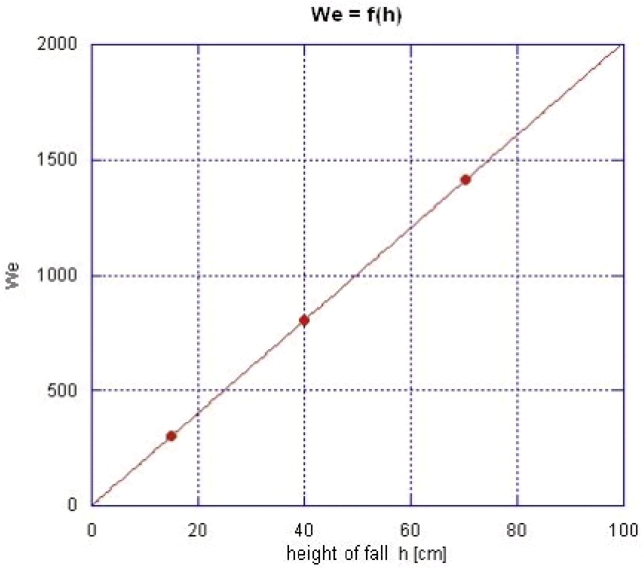

Fig. 4 We vs. height of fall

The test has been trained to change the temperature of the surface of impact. When the drop tries to growth it hasn't more a circular form, but it tends towards to flow by a preferential direction imposed by a set-up characteristic of the surface. So the first problem to solve is the choice of a new dimension. In our case, we have seen that the drop is more long and it signs up a new form like an oval and the accounting mount up between x axis and z axis.

The phenomenon has been observed on a temporal scale of 3 seconds, starting from the instant of impact, witch was assumed to be the very initial moment. There was no necessity to extend the interval of observation, holding the phenomenon dynamics to extinguish it a self as quickly as raising time.

So we have chosen the length of big axle shaft. The setting of parameters has been effected by the result obtained during the tweak. The lights have been put on with a corner of lamp socket equal to 100°, the camera has been fixed in front of the desk with a tilt angle equal to 55° and a distance point-plate equal to 40 cm.

With a distance ejector-plate equal to 15 cm,40 cm, and 70 cm, and it corresponds at the speed impact of the drops equal to 1.7 m/s, 2.8m/s e 3.7m/s, arranging the temperature of the plate for each height to 80°C, 95°C e 110°C.

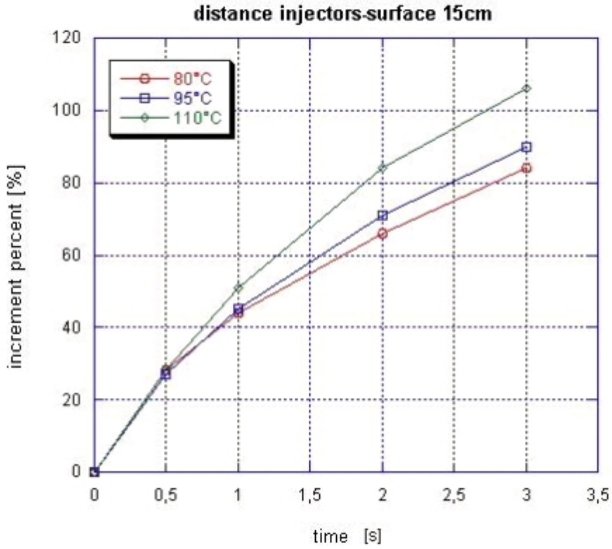

Fig. 5 Droplet area after the impact at different wall temperature at 15 cm of distance

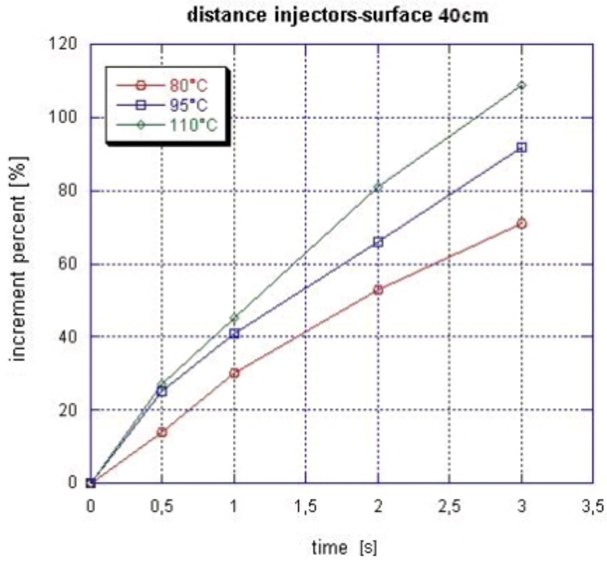

Fig. 6 Droplet area after the impact at different wall temperature at 40 cm of distance

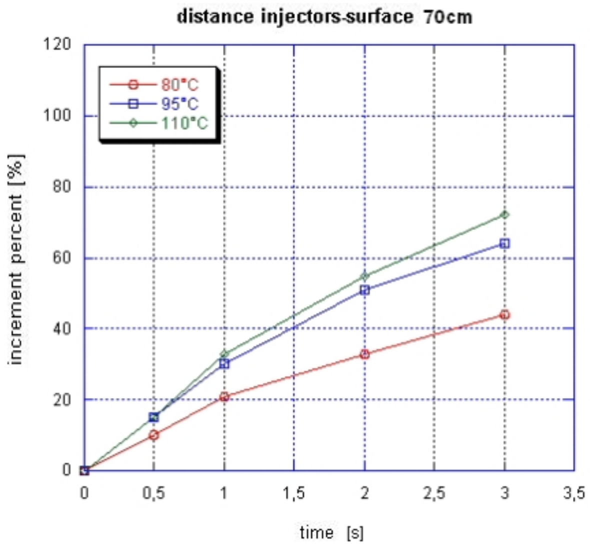

Fig. 7 Droplet area after the impact at different wall temperature at 70cm of distance

In every proves we have observed that, independently from the height of fall, that is from the speed of impact, the increasing temperature of the surface favors the phenomenon of the drop expansion The effect of the temperature is evident especially in the last stint of the observation interval (that is for long periods of times). This happens because the thermal trials are not instant trials, as a consequence, the drop reacts to the thermal effect caused by the plate after a certain interval of time.

In order to evaluate the effect of the impact speed[18] on the expansion it has been useful to operate a comparison among the proves performed to equal temperature of the plate for different heights of fall.

From the analysis of the schedules it has emerged that the impact speed effects both, the speed of impact influences both the dimension of the drop in the instant of impact, and the extension speed of the same drop to each temperature of the plate. That is to say, to more elevated speed of fall there must be an equal amount of initial dimensions but smaller rapidity of widening.

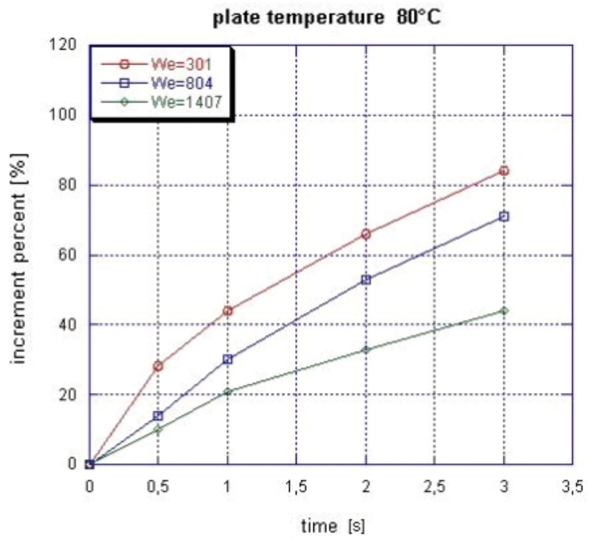

Fig. 8 Percentage increase of droplet area evaluated for calculated Weber number at wall temperature of 80°C

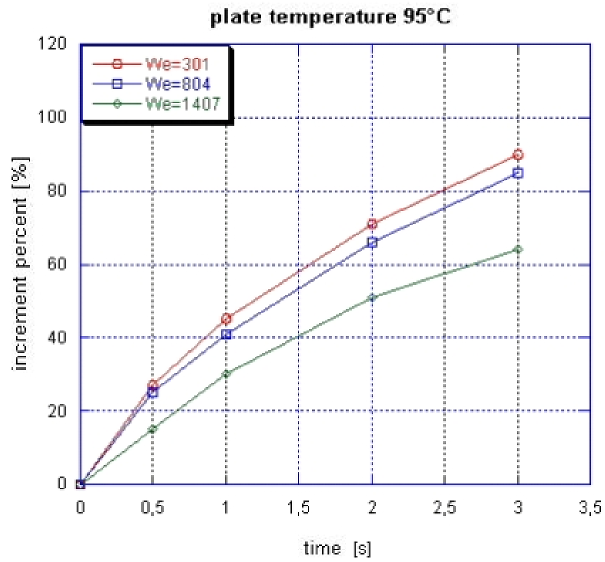

Fig. 9 Percentage increase of droplet area evaluated for calculated Weber number at wall temperature of 95°C

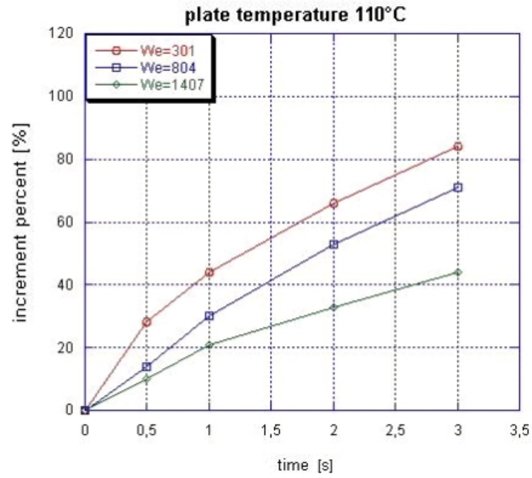

Fig. 10 Percentage increase of droplet area evaluated for Weber number at wall temperature of 110°C

3.3 Coalescence phenomenon

When two drops of liquid come close with an unimportant speed at the beginning , the Van der Waals strengths join the two drops and form a small liquid bridge. The bridge, thanks to its big bending, expands quickly under the effect of the superficial tension and the motion of the fluid leads to the formation of a sole greater drop, with a smaller whole surface.

Many theoretical and experimental texts about drops coalescence have been originated from its applications in industrial trials, like molding and processes of sintering Recent studies focus on its applications in the field of the microbiology reactions.

Eggers [11]elaborated an analytical pattern about the phenomenon of the coalescence among liquid drops under the action of the superficial tension, with reference to fluids in low stringiness. Under these conditions, Eggers proposed [12]a variation law about the liquid bridge thickness, founded on the followings simple physical considerations.

Assuming that the interfacial tension is $\frac{\sigma}{\Delta}$, whereas σ represents the superficial tension and Δ represents the smallest dimensions of the liquid bridge, it results that, balancing the kinetic energy and the interfacial tension the following equation:

$$\frac{1}{2}\rho v^2 \propto \frac{\sigma}{\Delta} \tag{1}$$

where ρ is the density and v the velocity of the fluid close to the bridge.

From these geometrical considerations he he has drawn:

$$\Delta \propto \frac{r_b^2}{2R} \tag{2}$$

where r_b is the thickness od the liquid bridge and R the ray of the droplet .

Follows:

$$\frac{1}{2}\rho v^2 \propto \frac{\sigma}{r_b^2/2R} \tag{3}$$

This relationship conducts to the following law of proportionality:

$$r_b^2 \propto \left(\frac{R\sigma}{\rho}\right)^{\frac{1}{4}} t^2 \quad (4)$$

The preceding law can be write again in the adimensional form introducing the characteristic time

$$\tau = \sqrt{\frac{(\rho R^3)}{\sigma}} \quad (5)$$

So:

$$\frac{r_b}{R} \propto \left(\frac{t}{\tau}\right)^{\frac{1}{2}} \quad (6)$$

For drops of water of diameter of 0.1 cm, such constant of time is worth around 4 ms.

Duchemin [10]has found, through numerical simulations on the coalescence of low-viscous fluids, a value of 1.62 for the constant of proportionality:

$$\frac{r_b}{R} = 1{,}62\left(\frac{t}{\tau}\right)^{\frac{1}{2}} \quad (7)$$

The bond of direct proportionality between the thickness of the liquid bridge and $\sqrt{t}$ it has experimentally been confirmed by various researchers that worked with different fluids.

Mingming Wu, Thomas Cubaud and Chih-Ming Ho [7]have studied the coalescence of two drops of liquid that come into contact in air with negligible speed..

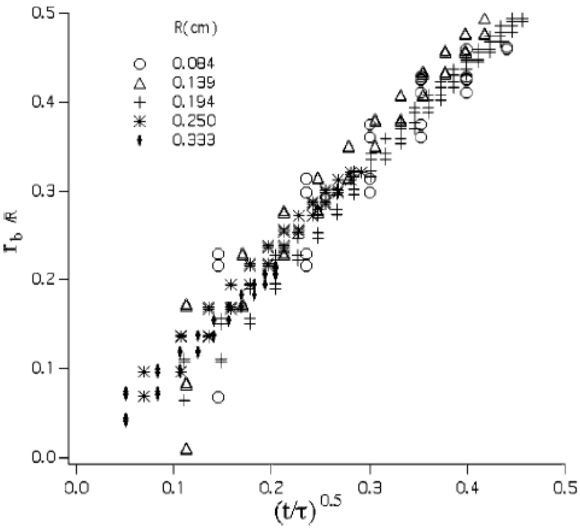

Fig. 11 Thickness of the liquid bridge vs. time

It is clear as the direct proportionality remains confirmed independently by the initial ray of the drops.

The same authors have concluded therefore that the ownerships of the fluid don't determine meaningful variations in the nature of the functional bond, also influencing notably the constant of proportionality and the characteristic time of the phenomenon.

Naturally only extending the investigation at different fluids it will be possible to confirm this hypothesis.

4 COALESCENCE OF TWO DROPS

Ss already describes the coalescence starts [13][6]with the formation of a liquid bridge among the two drops that it grows in the time up to reach of the same drops, so at a certain point they don't result more noticeable. In this process we find many parameters ; the purpose of this research is that to identify the most meaningful parameters and to characterize in a quantitative way their influence on the phenomenon. We check that an experimental approach to the problem it is essential.

The search is focused on the parameters related to the surface of impact, concerning the injectors and on the cinematic parameters of the drops. In particular the influence of the following parameters is analyzed:

- Temperature of the surface
- Speed of impact of the drops
- Distance between injectors
- Diameter of the drops
- Wrinkled ness of the surface

following we describe the different test.

4.1 Coalescence analysis (injectors distance equal to 8mm)

The first analyzed parameter has been the speed of impact of the drops, that has indirectly been regulated varying the distance nozzle -surface. Such distances are the same used for the tests on the single drop as it regards the value of temperature, the value of 80°C is chosen, temperature typical of a process of lubrication.

The distance between the injector and the hot plate has been initially chosen equal to 8 mm. Such value represents the least value obtainable in this phase of analysis of the parameters; to smaller distances in fact the phenomenon of the coalescence it happens with very fast dynamics, for which it results difficult to appreciate the influence of the other parameters on the trial.

The two nozzles have been set, in comparison to the surface, along the direction of the roughness of the plate. This favours the formation of the liquid bridge between the two drops, the expansion happening strongly along the direction that connects the two.

The characteristic dimension used for the quantitative study of the coalescence has been the thickness of the liquid bridge that is formed among the two drops. The time of observation of the phenomenon has been select equal to 1.5 s beginning from the instant of formation of the same bridge; to such value the bridge already introduces dimensions comparable to those of the single drops.

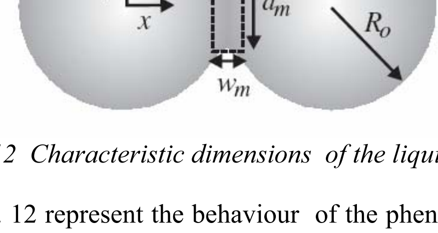

Fig. 12 Characteristic dimensions of the liquid bridge

The fig. 12 represent the behaviour of the phenomenon of coalescence obtained varying the heights of fall of the drops. The graphs have been drawn acquiring the images from the television camera CCD to a speed of 1000 frame/s and recording the phenomenon from the impact up to the complete coalescence of the drops. In this way it has been possible to analyze the growth and therefore the times of formation and disappearance of the bridge between the two drops. The correctness of the temporal instants of beginning formation of the bridge and its disappearance has been achieved through the treatment of images that has allowed the cleaning of the frames and therefore the correct extraction of the contours.

Then from the elaboration of the image[1][2][3][4]s it has been possible to draw the characteristic dimension of the bridge to the different instants of time.

From the graphs following brought it is deduced as the law of variation of the characteristic dimension of the in operation bridge of the time both of the type:

$$d = k(t)^{0,5} \qquad (8)$$

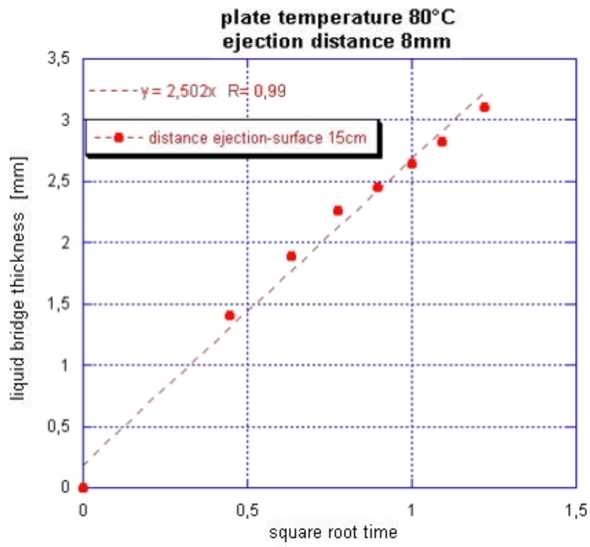

Fig. 13

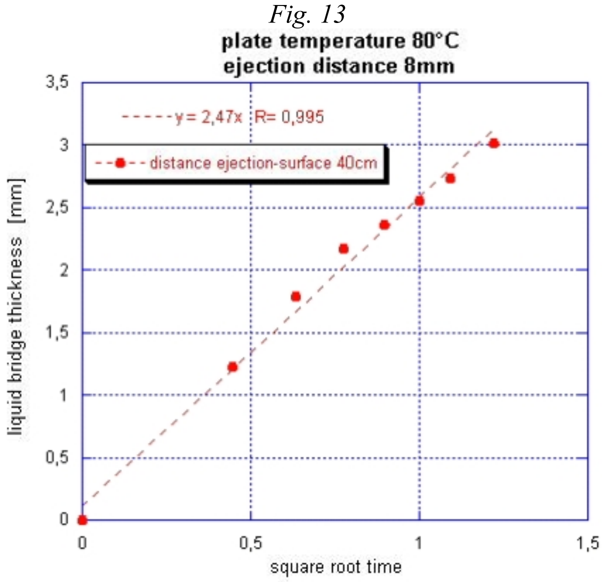

Fig. 14

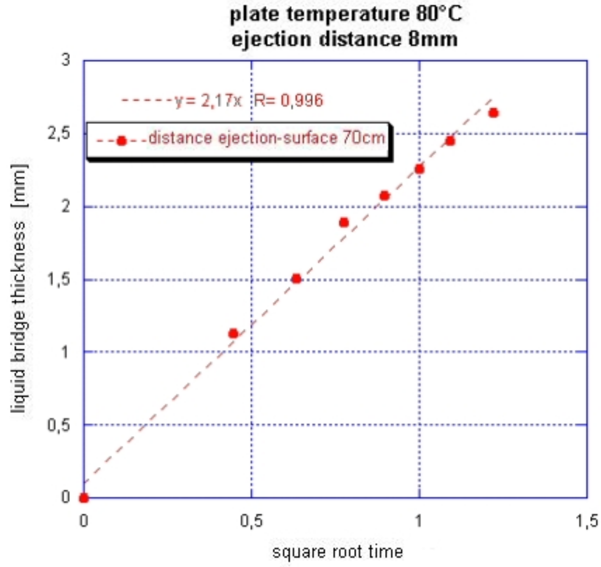

Fig. 15

Representing the thickness of the bridge vs. the square root of the time the results is a straight . Interpolating the points with a linear function a coefficient of correlation is obtained equal to 0.99 for all the diagrams. The curve of tendency, that allows to draw the constant k, underlines that such constant assumes different values in the three cases and precisely:

- for the distance injector-plate 15cm; k=2.502
- for the distance injector -plate 40cm; k=2.47
- for the distance injector -plate 70cm; k=2.17

4.2 Coalescence analysis (injectors distance equal to 10mm)

To verify if the behavior of the two impinging droplets change, changing the distance between the injectors, another series of trials have been made The temperature of the surface has not been varied in comparison to the preceding case. They are also developed in this case three tests to three different heights of fall of the drops, analyzing therefore the influence on the phenomenon of the speed of impact.

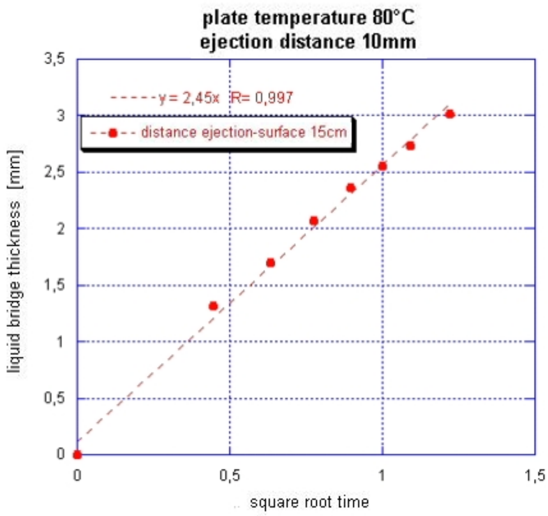

Fig. 16

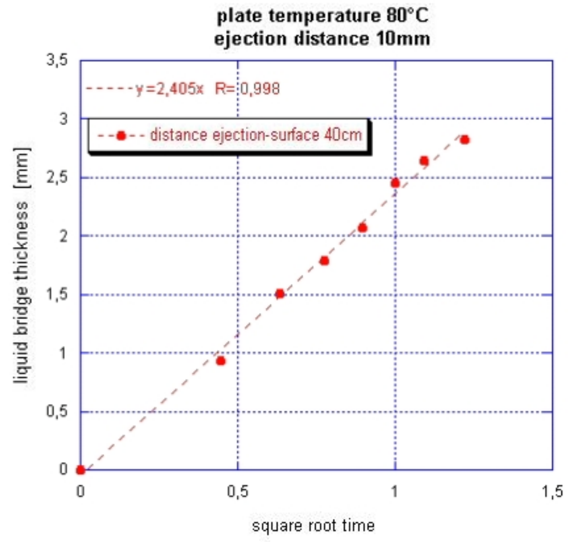

Fig. 17

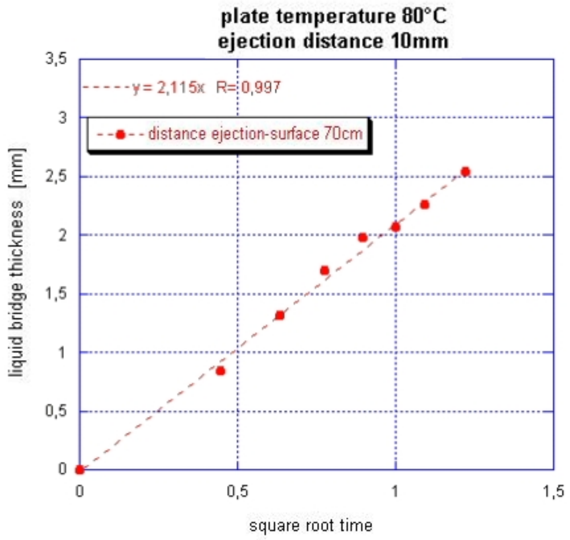

Fig. 18

Also in this case, representing the thickness of the bridge vs. the square root of the time, the results is a straight . Interpolating the points with a linear function a coefficient of correlation is obtained equal to 0.99 for all the diagrams. The curve of tendency, that allows to draw the constant k, underlines that such constant assumes different values in the three cases and precisely:

- for the distance injector-plate 15cm; k=2.450
- for the distance injector -plate 40cm; k=2.405
- for the distance injector -plate 70cm; k=2.115

5 CONCLUSIONS

To vary some speed of impact a direct proportionality has been found between the thickness of the liquid bridge and the square root of the time:

$$\delta \propto \sqrt{t} \tag{9}$$

This result is in accord with the available results in literature. Naturally the different conditions of test and the different ownerships of the fluids in matter (water and oil object of the tests) dlead that the absolute times of coalescence are very different; it is nevertheless remarkable the fact that the law of variation preserves the same form.

Increasing the speed of impact the constant of proportionality decreases. This result is a further confirmation of as elevated speeds of impact negatively influences the times of widening, and therefore on the coalescence..

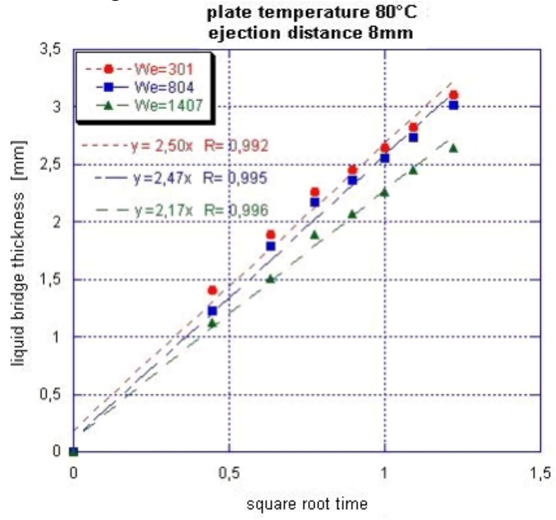

Fig. 19

This also happens with a distance among the nozzles equal to 10 mm.

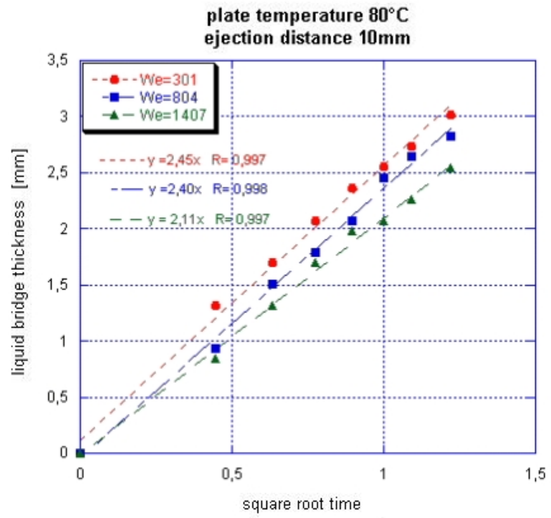

Fig. 20

The graphs in fig. 19 and 20 represent the values of the thickness of the bridge between the drops vs. the square root of the time for different values of the number of Weber.

Besides from the analysis of the different effected tests it is deduced that the law of growth of the liquid bridge is also valid for the lubricant in object and therefore for fluid highly viscous, in fact in all the experimented tests a dependence of the type is found

$$d = k(t)^{0,5} \tag{8}$$

To increase the distance between the nozzles, with equal speeds of impact of the drops, a diminution of the coefficient k can be observed , in other words decreases the rapidity of growth of the liquid bridge. The graphs in fig 21, 22,23 show, for every value of the speed of impact, a comparative behaviour of the temporal evolution of the liquid bridge for the two values of the distance between he nozzles.

.

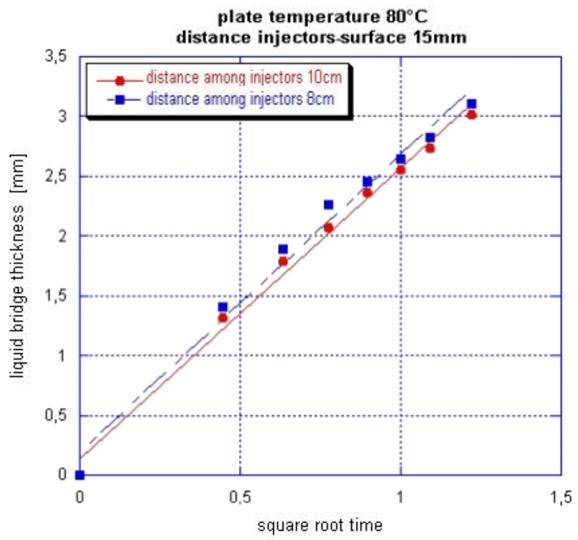

Fig.21

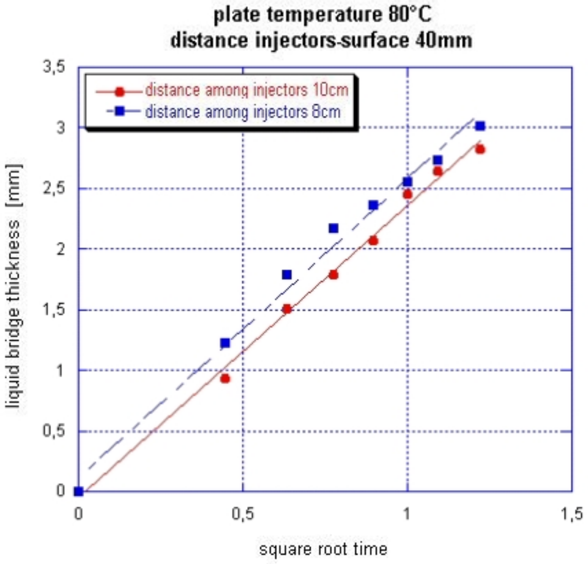

Fig.22

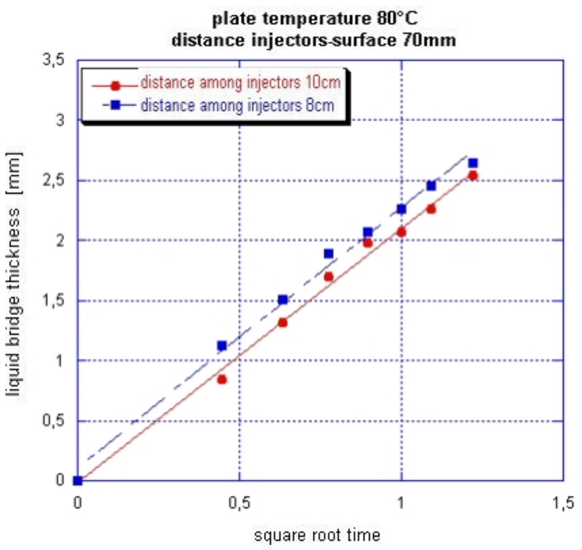

Fig.23

It is important to underline that to increasing the distance between the inject ors, not only the dynamics of growth of the liquid bridge him, but it also increases the time between the impact of the two drops and the instant of formation of the bridge, because each drop have to expand greater before entering in counted with the near drop. To have a rapid coalescence and therefore the formation in brief times of a continuous film of lubricant, it is important that the initial distances between the drops well be result, so much greater than the speed of impact of the drops .

6 REFERENCES

[1] Thomas Klinger, *Image Processing with LabVIEW™ and IMAQ™ Vision*

[2] Rafael C. Gonzalez, Richard E. Woods, *Digital Image Processing*, Prentice Hall.

[3] Thomas Klinger, *Image Processing with LabVIEW™ and IMAQ™ Vision*, Prentice Hall, 2003.

[4] G.W.Johnson, *LabVIEW™ graphical programming*, McGraw Hill ,1994.

[5] Bernard J. Hamrock, *Fundamentals of Fluid Film Lubrication*, NASA Reference Publication 1255 1991

[6] Dirk G. A. L. Aarts, Henk N.W. Lekkerkerker, Hua Guo, Gerard H. Wegdam, Daniel Bonn, *Hydrodynamics of Droplet Coalescence*, PhysRevLett.95.164503.

[7] Mingming Wua, Thomas Cubaud and Chih-Ming Ho, *Scaling law in liquid drop coalescence driven by surface tension*, American Institute of Physics, 2004, DOI: 10.1063/1.1756928.

[8] M. Ruger, S. Hohmann, M. Sommerfeld, G. Kohnen, *Euler/Lagrange calculations of turbulent sprays: the effect of droplet collisions and coalescence*, Atomization and sprays, Vol. 10, 2000.

[9] Alec Stokes, *Manual Gearbox Design*, Society of Automotive Engineers EINEMANN.

[10] L. Duchemin, J. Eggers, C. Josserand. *Inviscid coalescence of drops*, J. Fluid Mech. 487 , 167 (2003).

[11] J. Eggers, *Theory of drop formation* Phys. Fluids 7, 941 (1995)

[12] J. Eggers, *Breakup and coalescence of free-surface flow* , S. Yip, Editor, Springer 2005.

[13] Koch, Donald L., Bach, Gloria A., Gopinath, Arvind, *The transition between coalescence and bouncing of low Weber number aerosol droplets*, American Physical Society, 2000.