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Flammability Tests on Hot Surface for Several Hydraulic Fluids

Industrial equipment using hydraulic fluids are design to accept higher load and speed, implicitly higher temperatures, including for fluids. Leakages from enclosures like gear boxes or hydraulic systems could increase the risk of fluid reaching hot surfaces, thus producing fires hard to be controlled and isolated. The designer have to evaluate the flammability of fluids and they should select several solutions for a particular application in order to estimate the costs of different solutions and to mitigate the risk of having accidental fires due to a specific fluid grade.

The tests were done with the help of an original equipment allowing a dedicated soft assistance in order to protect the operator and to sustain reproducibility, according to the standard SR EN ISO 20823:2004 Petroleum and related products. The determination of the flammability characteristics of fluids in contact with hot surfaces - Manifold ignition test, There were tested the following grades of hydraulic oil HLP 68 X-Oil, HFC Prista, MHE 40 Prista (100% oil), a rapeseed oil (obtained after a dewaxing process) and an emulsion oil-in-water (5% vol. MHE 40 Prista). There were identified distinct behaviours of these fluids under the test conditions.

Keywords: *Fluid flammability, Hot surface, SR EN ISO 20823:2004, Emulsion oil-in-water, Hydraulic fluid.*

1. INTRODUCTION

European directives [2-4, 7] and other documents [1, 5, 6, 8] emphasis the necessity of reducing the flammability risk when using industrial fluids (hydraulic fluids, lubricants, processing fluids like those used in steel treatment and cutting etc.), especially in explosive atmosphere. Thus, “in particular, where fluids are used, machinery must be designed and constructed for use without risks due to filling, use, recovery or draining.” [7] Risk assessment implies a complex analysis of design, equipment, procedures and operators. Thus, the same document [7] underlines that “machinery must be designed and constructed to avoid all risk of fire or overheating posed by the machinery itself or by gases, liquids, dust, vapours or other substances produced or used by the machinery.”

Both manufacturers and users ask for tests that could certify fluid flammability characteristics, preferring ISO or ASTM standards [1, 10, 20, 21]. Many documents, including EU Directives, give recommendations to use standardised tests for estimating flammability of fluids [1-4, 6-8, 14-16]. The evaluation of fire resistance of a hydraulic fluid cannot be done by one test only and the aspects of fire resistance have to be pointed out by several tests, including those simulating on small scale the worst scenario that could happen in real applications using hydraulic fluids [11, 17]. Many of these tests give a result as “pass” or “not pass” [8, 20, 21]. The fluid that passed a particular test or, better, a set of tests, is included in recommendations or approvals, but these ones are specific to regional or national reglementations [1, 6, 8, 13].

2. TESTING PROCEDURE

The tests were done with the help of an original equipment (Fig. 1) [27] allowing a dedicated soft assistance in order to protect the operator and to sustain reproducibility, according to the standard

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SR EN ISO 20823:2004 Petroleum and related products. Determination of the flammability characteristics of fluids in contact with hot surfaces - Manifold ignition test. This test simulates an accident or the hazardous event when a fluid drops on a hot surfaces: 10 ml of fluid is dropped during 40…60 seconds on a manifold kept heated at a constant temperature, from a distance of 300±5 mm above the manifold surface. For each temperature and fluid there were done 3 tests. The highest temperature, for which the fluid does not burn or ignite, was established is the same "verdict" was obtained for all the three tests. All the temperature values given in this study have the accuracy given in Figure 2. The equipment is controlled and assisted by a PC with a dedicated soft in order to protect the operator from being near the heated zone. Figure 2 presents the display of the soft.

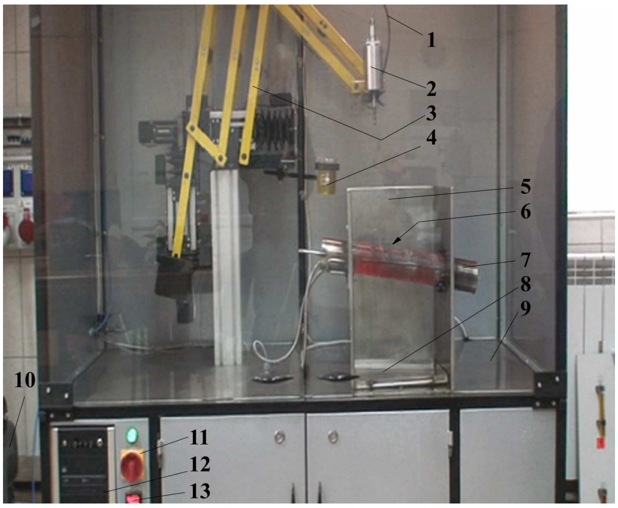
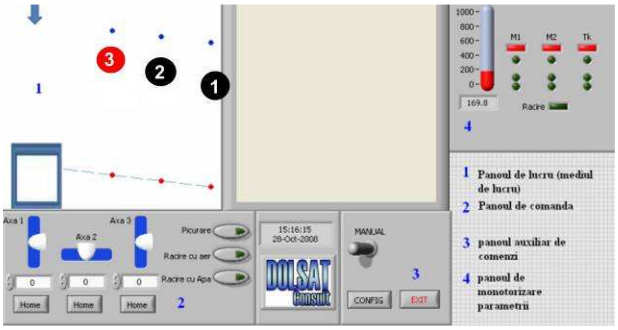


Figure 1. The equipment for testing the fluid flammability on hot surface. 1 – piping for cooling system of the dispenser, 2 – dispenser with cooling mantle, 3 – 2D robot, 4 – glass for the tested fluid, 5 – metallic box, 6 – temperature gauge protected by a welded case, 7 – the heated manifold having inside an electric resistance, 8 – tray for collecting the drops, 9 – ventilated enclosure, 10 – air compressor, 11 – the main switcher, 12 – the hard of the assisting PC, 13 – display for the manifold temperature

There are several reasons of fluid leaking [11, 16]:

- fatigue of the system elements, under normal or severe exploitation (cracks, creep, ageing), or due to an adequate maintenance,
- cyclic or accidental thermal expansions, bolts stretch;
- changes of fluid properties due to exploitation, especially temperature rising that makes the fluid to become thinner,
- the efficiency loss of seals and hoses in time, due to their modifications produced by long exposure to temperature or/and chemicals, but also by trapping "foreign" particles (solid, liquid, gaseous or mixtures of them);
- screw-up operations: a controlled mounting and a preventive maintenance decrease the leak probability under functioning conditions. It is also important to respect procedures for starting and stopping the equipment;
- operator's faults; regular trainings could significantly reduce these events [8, 11].



1 Panoul de lucru (mediul de lucru)
2 Panoul de comanda
3 panoul auxiliar de comenzi
4 panoul de monotorizare parametrii

Figure 2. Positions 1 are 2 could be heated at the test temperature with the high accuracy imposed by standard (±5ºC). The accuracy for position 3 is (±6.3ºC).

There were tested the following grades of hydraulic oils HLP 68 X-Oil [25], HFC Prista [23], Shell Irus Fluid DR 46 [22], a rapeseed oil (obtained after a dewaxing process) [9] and an emulsion 5% MHE 46 in water as recommended by Prista producer [24]. There were identified distinct behaviours of these fluids under the test conditions.

Shell Irus Fluid DR 46 is a tri-aryl phosphate ester fire resistant hydraulic fluid. It contains carefully selected additives to give superior oxidation and hydrolytic stability. Shell Irus Fluid DR 46 should be used in hydraulic systems operating in close proximity to potential ignition sources. This includes equipment such as die-casting machines, billet loaders, electric arc furnaces, forging presses and others operating in fire hazard situations.

PRISTA HFC is a fully synthetic fire resistant water-glycol based hydraulic fluid blended with an additive package to improve the anti-wear properties and corrosion protection of the finished product [23].

HLP 68 X-Oil [25] is an optimized alloyed hydraulic oil with a high performance level and a broad field of industrial application. It especially distinguishes with good viscosity-temperature behaviour, high ageing stability and reliable corrosion protection. Additives provide an excellent wear protection under extreme loads, too. The behaviour against sealing materials is neutral.

Prista MHE-40 is used as 5% working fluid in oil-in-water emulsion for hydraulic systems with high risk of flammability [24]. The tests were done on the fully mineral oil and for the emulsion 5% MHE 40 (vol.) in water.

Table 1. Flammability characteristics of the tested oils

Fluid	Flammability characteristics		
	Flash point	Fire point	Refe-rences
Shell Irus Fluid DR46	245	335	[22]
HLP68-XOIL	238		[25]
Rapeseed oil	270	216...346	[26]

From Table 1 one may notice that the two characteristics, the flash point and the fire point, do not give any starting point for evaluating the flammability on hot surfaces [12, 18, 19]. For instance, the fire point value for Shell Irus Fluid DR 46 is included in the range also reported for rapeseed oils [26], but the first one does not burn on hot surfaces even at the maximum test temperature imposed by the ISO standard (700°C±5°C), the tested rapeseed oil burning when being dropped on a surface heated at 551±5°C.

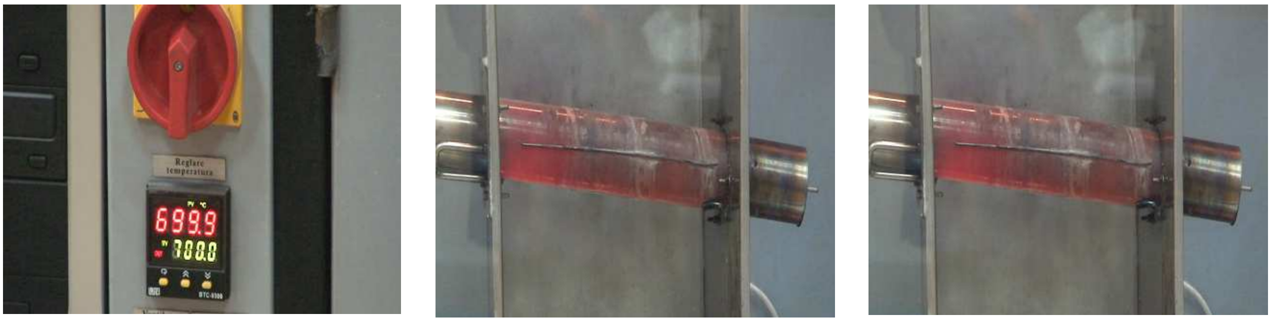
3. RESULTS AND DISCUSSION

Analysing the recorded films of the tests (Figs. 3-10), the authors noticed the followings: there were stages when the fluid only evaporates or change structure without ignition, these being useful in establishing the time response of fire/security sensors.

The hydraulic fluids HFC Prista, Shell Irus Fluid DR 46 and the emulsion 5%MHE Prista in water does not burn even for the highest tested temperature (700°C±5°C), a temperature also included as imposed for hydraulic fluids with the best behaviour under the conditions of EN ISO 20823:2003. The other two tested fluids burn. The rapeseed oil has 551°C the highest temperature at which it does not burn for repeated test (at least three) and HLP 68 X-Oil has for the same parameter the value of 500°C.

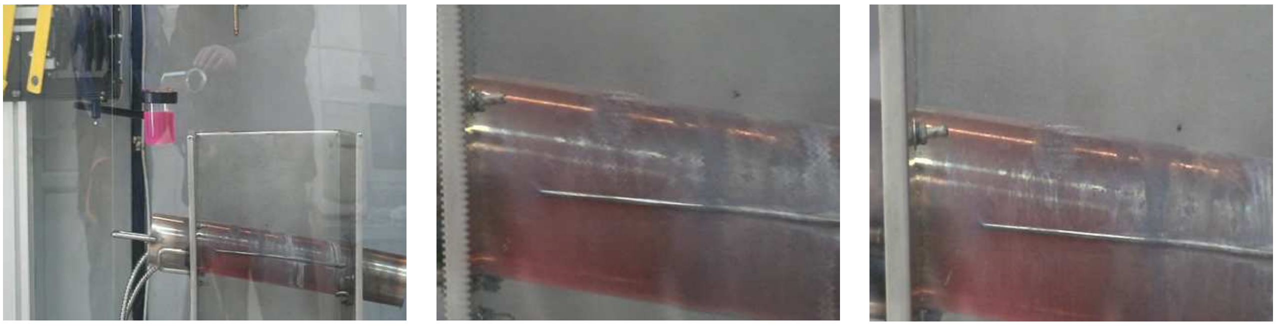
36th second　　37th second　　38th second

Figure 3. Three consecutive seconds from the film recorded for the fluid HLP 68 X-Oil, tested at 515°C



50th second　　52th second

Figure 4. Images from the film recorded for the fluid Shell Irus DR 46, tested at 700°C

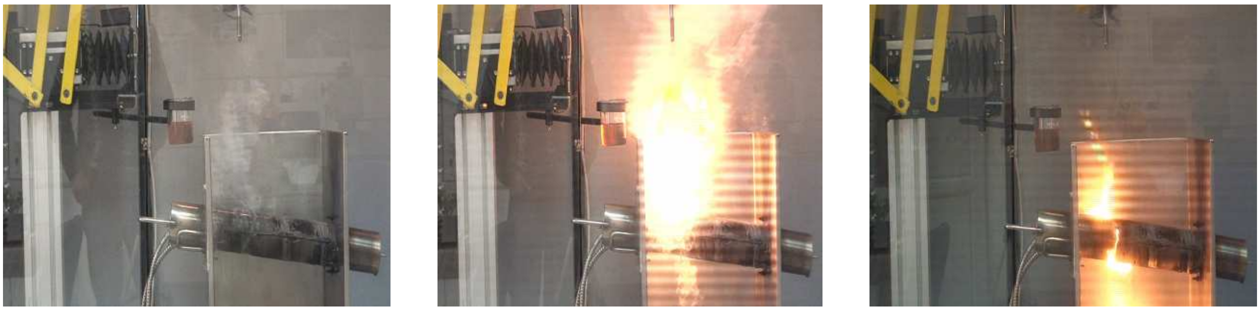


20th second 21th second 23th second

Figure 5. Consecutive images from the film recorded for the fluid HFC Prista, tested at 700°C

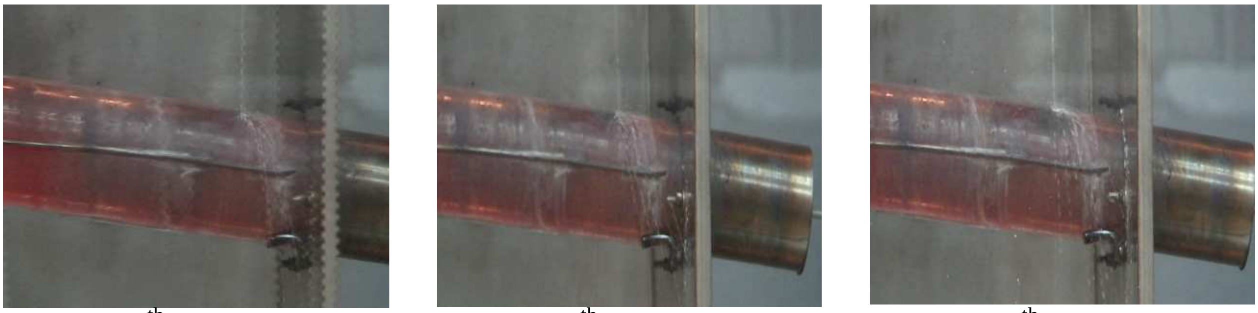
2th second (first drop) 3th second 7th second

Figure 6. Three images from the film recorded for the mineral oil MHE 40 Prista tested at 450°C



2th second (first drop) 5th second 40th second

Figure 7. Images from the film recorded for the mineral oil MHE 40 Prista, tested at 460°C

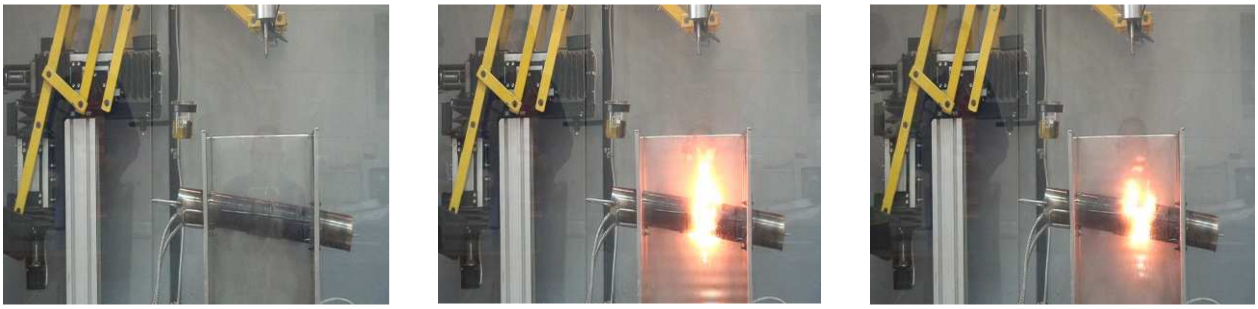


4th second 5th second 10th second

Figure 8. Images from the film recorded for the oil-in-water emulsion (5% MHE 40 Prista oil vol. in water), tested at 700°C

38th second   46th second   47th second

Figure 9. Images from the film recorded for the rapeseed oil (dewaxed grade), tested at 551°C



38th second   39th second   40th second

Figure 10. Three consecutive seconds from the film recorded for the rapeseed oil (dewaxed grade), tested at 574°C

The behaviour of this rapeseed oil (dewaxed grade) [9] under the testing conditions imposed by SR EN ISO 20823:2003 could be grouped in the following ranges, characterised by temperatures for which the fluid behaviour is the same :

1. a temperature range for which there are repeatedly obtained the same results when testing the fluid on hot manifold (200…551ºC, the fluid does not burn);
2. a temperature range for which the test results is randomly different (in one test the fluid does not burns, but in the following one it is burning and so on): 551…557ºC; in practice it could be included in the range for which the fluid burns and the use of the fluid in this range is strongly not recommended;
3. The temperature range for which the fluid burns, $\theta > 560$ºC.

Any test is irrelevant for the temperature range 552…562ºC for the dewaxed rapeseed oil because the difference (10°C) is the same to the allowance range (±5°C).

The flammability risk could be substantially reduced by using emulsions as that one obtained from 5% vol. MHE 40 in water. The authors noticed that this emulsion does not burn on the surface heated at 700°C, but the mineral oil – 100% MHE 40 Prista does burn at a much lower temperature of 450°C and it is very sensitive to the surface quality. The authors also noticed that the test done at this temperature of 450°C gives inconsistent results. From 9 tests, during 6 ones, the fluid ignited and burnt when it was dropped on the clean surface of the heated manifold. When the test was done on the same manifold, but dirty from previous tests, the temperature of ignition of the same fluid was even lower: 415°C. This is a conclusion that could be the subject of a further investigation, as in practice many surfaces could be far for being clean due to the technological process or, worse, due to the "leak" of operators' responsibility or an inadequate maintenance.

The designer has two possibilities for reducing the flammability risk: to use a fluid that does not burn or to change the design in order to have a better protection against hazardous events that could cause fluid ignition. Of course, the first solution is better especially when the equipment works in a particular environment, including mining, metallurgy, glass industry etc. The designer has to select the hydraulic fluid from families like the synthetic, mineral or that of emulsions. The synthetic ones have some advantages, but they are still expensive. The engineer has to balance the advantages and disadvantages of each group. For instance, the emulsions could be much less expensive, but they have to be circulated in systems (piping, pumps etc.) exhibiting a good corrosion resistance or, at least, an acceptable resistance for a particular application.

4. THE COLOUR CODE

The authors proposed a code of colours to be written on the oil label in order to emphasis the flammability on hot surfaces [28]: blue for the temperature range the fluid does not burn and red for the temperature range the fluid ignites and burns. Figure 11 presents such possible labels for the tested fluids. Of course, the label includes the standard procedure used for testing the flammability (SR EN ISO 20823).

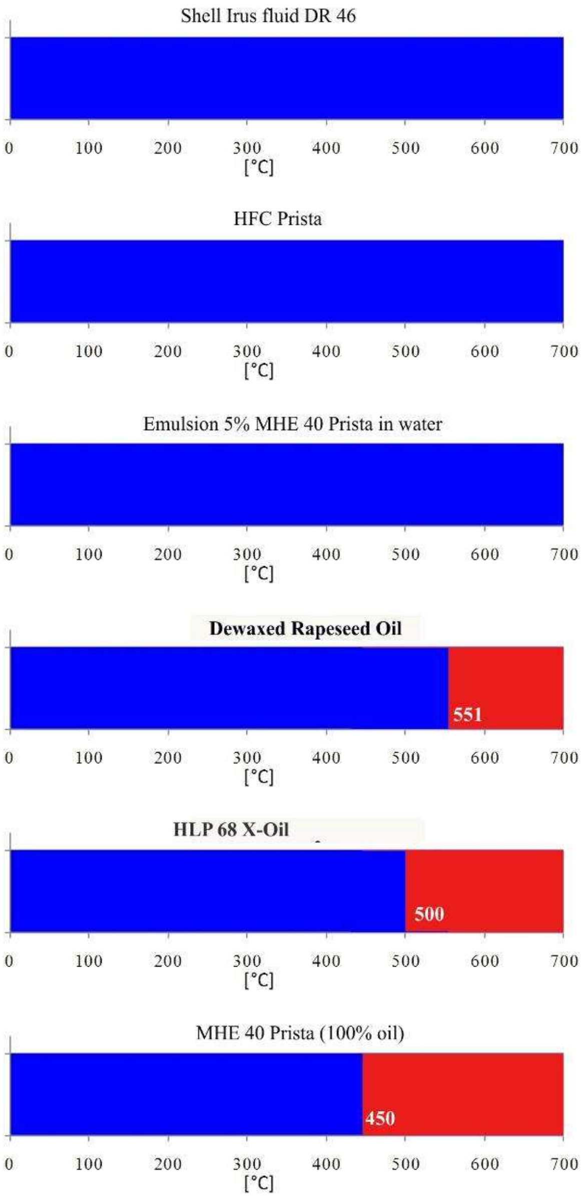


Figure 11. The label proposed by the authors for the tested fluids

5. A RISK INDEX RELATED TO FLUID FLAMMABILITY ON HOT SURFACE

In some cases the designer could apply risk index method, calculating a risk index, as:

$$I_{risk} = \sum_{j=1}^{n} a_j \cdot r_j \qquad (1)$$

where a_j is the attribute j related to risk evaluation (for instance, ignition temperature on hot surface, smoke production, electrical ignition sources etc.), $j=1,\ldots,n$, and r_j is a value associated to likelihood of occurrence and consequences. r_j may have the following values: 0 – the occurrence is not credible, 1 – unlikely, 2 – medium probability, 3 – highly likely [9, 13]. The attribute of ignition on hot surfaces could be related to the ignition temperature of the fluid involved, but in an indirect proportionality to this one. For instance, if the engineer had to select an industrial fluid among several with different hot surface ignition temperatures, $T_1 \langle T_2 ... \langle T_n$, after tested under the procedure of ISO 20823, he would calculate the attribute a_j as following:

$$a_j = T_n / T_j \qquad (2)$$

T_n could be the maximum temperature for which the test for flammability on hot surface is recommended in SR EN ISO 20823 (700±5°C).

It is obviously that a lower value of this attribute (even 1 for fluids that do not burn at 700°C) is desired for a safe functioning and for a very low probability of hazardous events. The problem to be solved is the compromise between the initial costs and the performances of the selected fluid. Several decades ago the ratio between high security fluids and hazardous fluids was as great as 5...3 to 1. A fluid-power system will be more expensive when using water-based fluids due to the materials involved in designing (especially corrosion resistant steels, sealings etc.) as compared to a system with similar performances but using mineral oils. As the tests proved, a safe solution is to use oil-in-water emulsions, but the designer has to balance very well the advantages and disadvantages of this solution and to know the consequences of using such a hydraulic fluid class, including compatibility of emulsions with all the materials they come into contact (steel parts, sealings, other fluids, operators etc.), supplementary furniture for maintaining the emulsion characteristics (dispersion quality, concentration etc.).

6. CONCLUSIONS

There is no test ensuring a high level of safety for fire resistance but a particular set of tests, selected after a well-documented risk assessment could give a better solution.

The determination of fluid flammability on hot surfaces imposes particular solutions for improving the security of the designed system, including fluid selection, avoiding scenarios with hot surfaces near piping and hoses etc.

The list of hydraulic fluids possible to be selected and the tests that these fluids have to pass, will have to be known and set even in the design stage of the equipment. It is also important to analyse similar accidents related to the real applications in order to notice possible improvements in equipment, process and environment control and for workers' training.

These analyses may be useful for designers in order to better assess the risk and to estimate costs of different solutions implying different grades of hydraulic fluids.

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