Dripping and jetting from pipe wall leakages in cross flow fouling

Nicholas Applin*[1], Nicolas Miché[1], David Mason[1], Marco Marengo[1]
[1]School of Computing, Engineering and Mathematics, University of Brighton, United Kingdom
*Corresponding author: n.applin@brighton.ac.uk

Introduction

Much effort over the years, particularly in the field of filtration, has been put towards the study of the fouling mechanisms of individual suspended components in liquid flows [1]. However multi-species (also known as polydisperse) liquid-solid flow conditions have been less commonly studied by the research community. This knowledge gap requires further research, as the use of multi-species fouling particles has been used as a successful strategy to seal unwanted leaks in fluid systems in many industrial applications. Often, a suitable formula is derived by a trial and error basis (which is unlikely to be optimised) with no attempt to understand the physics of the fouling mechanisms involved. One area of application is in the industry of automotive coolant system leak repair additives. There is no fundamental knowledge of the sealing mechanisms, which govern these aftermarket additives. This paper aims to contribute to the understanding of multi-species fouling mechanisms by providing data obtained from experimental investigation of cross flow fouling by multi-species solid particles in a liquid phase. The experimental apparatus was devised to allow the study of the fouling mechanism of circular holes (leak site), which have diameters in the range of 127 to 635µm, over a range of fixed operating conditions (as shown in Table1).

Table 1. Summary of test operating parameters.

Test operating parameters	Operating test points				
Leak site hole diameter [µm]	127	254	381	508	635
Fluid temperature [°C]	30	50	70	90	110
Fluid pressure [kPag]	35	70	105	140	175
Fluid Average velocity [m/s]	0.25	0.5	1	2	3
Ethylene glycol concentration (in water) [% v/v]	0	30	50	70	100
Fouling agent concentration [% v/v]	0.05	0.10	0.15	0.20	0.25

The fouling particle size distribution ranges from colloidal suspensions (which may be as small as) 1nm to large particle suspensions of 850µm. This distribution can be considered Gaussian over the range of 63 to 850µm.

Material and methods

The test program was based on 30 different combinations of the operating conditions shown in Table 1. For each test combination a single operating test point was fixed for each parameter for the duration of the test. Each test combination was repeated 3 times, which required 90 tests in total to be completed. The test apparatus is shown in Figure 1; all the equipment outside of the dashed line box is required for the conditioning of the test solution, so that each operating parameter is held at its required test point during each test. The equipment inside of the dashed line box is required in order to perform the leak sealing measurements. This consists of a visualisation tube, having a square internal cross-section of 10 by 10mm, which facilitates the mounting of interchangeable test plates (manufactured from brass shim having a thickness of 0.25mm). These test plates are used to provide calibrated circular leak sites of diameters ranging between 127 and 635µm. The design of visualisation tube is such that the calibrated hole location is at least 40 diameters from the visualisation tube entrance. This is to ensure that the flow is fully developed when it reaches the calibrated hole (leak site). The “leak sealing performance measurement” uses two simultaneous measurement methods which gather data from the external flow (i.e. the fluid being expelled into the ambient atmosphere from the leak site). The first method utilises non-intrusive high speed (200fps) shadowgraph photography technique and MATLAB image analysis to obtain an instantaneous normalised total fluid loss area within the region of interest. From this data the time of the regime changes from a free jet, jet break-up (with ligaments) and dripping can be determined as a seal is formed during a test. An example of this data is shown in Figure 2.

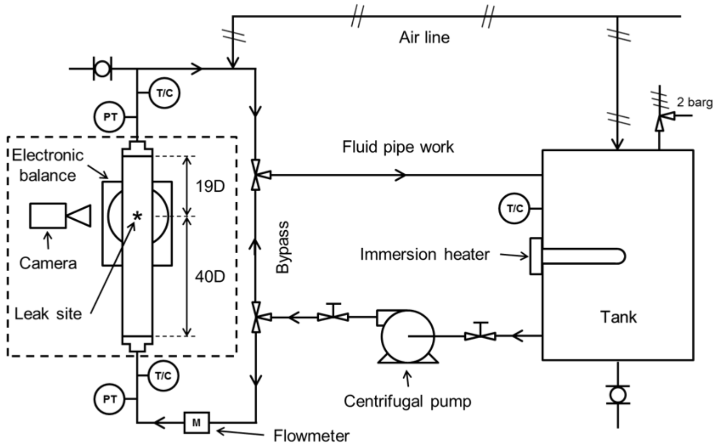

Figure 1. Test apparatus

The second method employs a leak rate characterisation (mass flow rate) technique by data logging at 20Hz; the cumulative fluid mass loss of the fluid exiting the leak site from an electronic balance placed directly beneath the leak site. The fouling agent (as shown in Table 1) composition and particle size distribution were kept constant for all tests during this study. The fouling agent was prepared in-house, to form a repeatable representative sample of a commercially available leak repair product, free from potential manufacturing variations. The composition of the fouling agent was controlled by accurate weighing of the constituent ingredients with electronic balance and the particle size distribution profile was controlled by accurate weighing of each pre-sieved particles size band.

Results and Discussion

The data obtained from the experiments will be used to assess if single-species smaller scale empirical dead-end filtration fouling models as summarised by Blankert [2] can be adapted to the multi-species cross flow case.

Note that in Figure 2 the start of dripping regime occurred at ≈9 seconds from the start of the test, with its distinctive sawtooth pattern caused by the gradual increase in the droplet cross-section area, as an individual droplet grows on the test plate surface and the relatively fast process of the droplet departing from the plate surface due to the droplet increase mass overcoming surface tension forces.

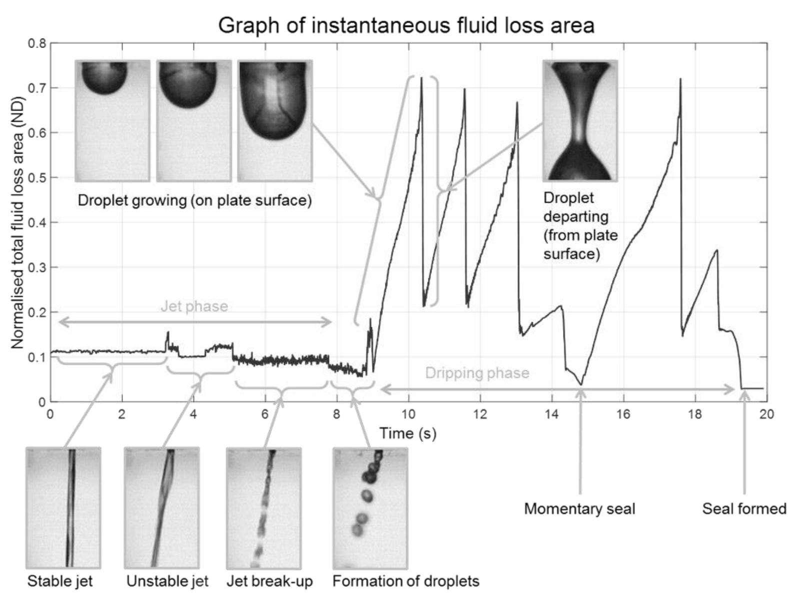

Figure 2. Example of instantaneous normalized total fluid loss area data.

References

[1] Le-Clech, P., Chen, V. and Fane T.A.G., *Journal of membrane science* 284:17-53 (2006).

[2] Blankert, B., Betlem, B.H.L. and Roffel B., *Journal of Membrane Science* 285:90-95 (2006).