Two sets of technical comments on P. Kessener, "The aqueduct at Aspendos," *JRA* 13

1. by Deane R. Blackman

Kessener's comprehensive and scholarly contribution, which bravely tackles the basic science in some detail and which will surely be an enduring reference, nevertheless perpetuates some technical misunderstandings that recur in the literature. I begin with the term "siphon".[1] It is unfortunate that this term continues to be used.[2] The term applies to the situation when, at some point in a closed conduit, the hydrostatic pressure is less than atmospheric. It is not just that the overwhelming proportion of the innumerable pipe systems in the world never know sub-atmospheric pressure and should not be confused with this unusual arrangement, which warrants a technical term of its own (indeed, many modern textbooks do not mention siphons); but to introduce the term inappropriately also leads to misleading reporting and misconceptions. When we reach the discussion of the hydraulics of this system, *real* siphons find their way into the argument (p. 125), though the evidence shows that there was no siphon at Aspendos. The presence of air pockets and so on is almost irrelevant to operations if no point in the system lies above the Hydraulic Grade Line; were it not so, no garden hose would work reliably.

It is quite true that the problems of getting a siphon to start and to keep it running are significant: even without leaks, air tends to come out of solution and will eventually destroy the liquid column.[3] But in a pipe system which does not go sub-atmospheric, the inverse (if we might dare to use the word) applies: air trapped at a high point will tend to be taken into solution, and the confused internal flow at such a point will be very efficient at entraining and so removing air. Just as a garden hose may splutter when first turned on, very rapidly all air is expelled from the system and there is no question that flow will eventually be established without further intervention.

This topic leads Kessener to a discussion of internal roughness and to water hammer (p. 126). These are essentially independent subjects. Significant roughness elements — the example used is mortar at a pipe join which has been extruded into the pipe section — do not lead to air pockets; they do lead to greater hydraulic loss and, in extreme cases (though almost certainly not in this case, because the velocities are too small), can produce cavitation, a phenomenon which is quite unrelated to, and does not involve, the presence of air. The statement about the causes of water hammer are accurate, but the consequences are not accurately pursued. An air pocket, evanescent on account of a leak, may be spectacular, but it would not lead to a significant change in velocity in the water column and hence would not lead to an hydraulic surge of any consequence. There is a misunderstanding, too, about the way water hammer is manifest. One produces a positive pressure wave, which might loosely be termed a shock-wave, by slowing down the water column; that wave also may well be reflected from back upstream as a negative pressure wave. There is (almost) no actual movement of water in any of this — it is the wave fronts which move, not the water (a difficult concept to grasp) — and, contrary to the discussion on p. 127, an air pocket in the pipe large enough to break the water column will reflect any incident positive pressure wave[4] as a negative one and hence limit the region affected.

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1 Appearing first in the title: "The aqueduct at Aspendos and its inverted siphon," *JRA* 13 (2000) 104-32. By the fourth paragraph of Kessener's article the system at Aspendos has become simply a siphon and (with occasional lapses into accuracy) remains so.

2 The word derives from one sense of the original Greek, an apparatus for drawing wine from a cask.

3 To quantify this, H. Addison, *A treatise on applied hydraulics* (3rd edn. 1944; repr. 1950) 202, gives the rate at which air will come out of solution as about hq litres per hour, where h is the sub-atmospheric head (m) and q is the volume (m^3) in the pipe which is sub-atmospheric.

4 To explain this term for the non-specialist: waves on a pond are a reasonable analogy to these pressure