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A catalytic catastrophe, a quarter-century on, compared with earlier chemical and materials failures

Technological failures generally

The author "collects" historical technological failures, and indeed has witnessed some technological failures at first hand.

He classifies these failures as follows:–

(i) Failures resulting from pursuing a good idea for which the supporting technology or the marketplace is not, in the event, ready.

(ii) Failures after which one wonders, "How on earth could anyone competent have thought that what was done could be effective/economic/safe?"

Failures in category (i) are the price paid for successful innovations: good ideas will always encounter unexpected snags, and only some will survive being tried out.

Brunel's leather (1846-1848); Pilkington's float glass (1952-1959) as a counterinstance

In category (i) of failures, the author places the construction of an "atmospheric railway" by the British engineer Isambard Kingdom Brunel (1806-1859) [1]. Contemporary steam locomotives were slow on steeper inclines, because of the mass of the locomotive and its fuel. A possible solution was to separate the consumption of primary fuel from the locomotive (as was later achieved in electric trains). In Brunel's day, although the railways used electric *telegraphy*, electric *locomotion* was not yet an option.

Pneumatic locomotion *was*, however, an option. Brunel laid a pipe 15 inches (38 cm) in diameter between the rails of his line. In the pipe travelled a piston connected from behind to the first carriage of the train, which replaced the normal steam locomotive. Ahead of the piston, the pipe was pumped out to 16 inches of vacuum (*ie* down to 0.53 bar). Behind the piston, the pressure was atmospheric, so that the piston was propelled forward with a calculated force of *ca* 0.5 tonne weight. Running along the entire upper side of the pipe was a longitudinal valve of the best oxhide leather riveted to iron reinforcement, with a soap-based sealant. The valve was closed ahead of the piston, while behind the piston it opened for the connecting arm from the piston to the carriage, and closed after the connecting arm passed. The track was in sections averaging 4.5 km long with steam-powered air pumps alongside the track where the sections ended.

Brunel's atmospheric railway was the westward extension ("the South Devon Railway") towards Plymouth of the conventional railway from London Paddington to Exeter (completed in 1844). After initial difficulties, the extension operated "atmospherically" from September 1847 to January 1848 between Exeter and Teignmouth, and thereafter as far as Newton Abbot, over a total track length of 31 km. Parts of the system beyond Newton, with pipes 22-inch (56 cm) in diameter, had already been constructed when, in June 1848, it was discovered that from Exeter to

Newton the valve leather had seriously degraded through the effects of vacuum, winter, and chemical reactions. Regular, expensive replacement of the valve would alone have rendered the atmospheric railway uneconomic. On Brunel's advice, the atmospheric equipment was sold off (some as scrap) and conventional steam locomotives were used over the entire line from Exeter to Plymouth (reached in April 1849). The railway company had suffered, according to Rolt, "the most costly engineering failure of its time".

Any chemist in 2020 (or indeed 1920) would of course say that the leather should have been tested for medium-term degradation under simulated conditions, not in the course of full-scale field use. But nevertheless, Brunel had not been alone in thinking atmospheric railways would work, which is why the author places this failure in category (i).

An instructive comparison can be made with the *successful* development of the float glass process by the UK company Pilkington Brothers [2]. Before the float glass process, large sheets of distortion-free parallel-sided glass, *eg* for shop windows, were made by precision-grinding inferior glass sheet on both sides, which was expensive. The *principle* of the process, proposed in 1952, was simple: if one floats molten glass on molten tin, it becomes flat under gravity. Tin recommends itself because (a) it is readily available, (b) it is dense enough to support glass, and (c) it has a very low vapour pressure at the temperatures required so that it does not distil off and condense in undesired places. Tests were made, a pilot plant was built, and finally a full-scale plant.

Numerous problems were encountered including chemical ones: contamination of the glass by the spout from which it was poured, molten, onto the tin; and the reaction of parts per million of oxygen and sulfur with the tin, affecting the glass. It was *14 months* before the full-scale production plant first made glass of saleable quality. Pilkington announced their success in 1959, after which the process was licensed worldwide. Whereas for Brunel to have persisted after June 1848 would have been folly, in this case brave persistence resulted in success.

NASA's rubber 1986

This section of the paper, and the next, final section, deal with category (ii) failures, ones that one feels contemporary scientists and engineers should have foreseen and prevented.

Particularly notorious and well documented [3]-[5] is the disaster of NASA's space shuttle system on 28 January 1986, killing the crew of seven in the orbital vehicle *Challenger*. The orbital vehicle was a winged craft which went into orbit, later to renter the earth's atmosphere and to glide back to earth. For launch, it was attached to a huge external fuel tank containing liquid hydrogen and liquid oxygen which umbilically supplied the orbital vehicle's motors. The tank was attached in turn to two solid fuel rocket boosters. The boosters and the external fuel tank were jettisoned, in that order, before the mission in orbit began. Each booster was assembled at the launch site, with three sections jointed at their outer metal casings. The joints contained O-rings of speciality rubber, 3.7 m in diameter and 6 mm thick, intended to seal in the pressures generated as the solid fuel burnt. These were

"Criticality 1" components, for if the relatively cool gas at the outside of the booster got past them, that gas would soon be followed by hotter gas and flame. Now, even at the launch site in Florida it could be cold in winter. The night before the launch, the ambient temperature had fallen to -13 ^{o}C, so the metal casings and rubber must have become very cold and would be slow to warm up the next day. It was known from previous launches that the O-rings performed best at ambient temperatures on launch above 17 ^{o}C. No tests had been made on the rubber under conditions similar to those which actually would apply the next day. On launch at 11.38 am, a shower of ice came from the launch platform. Virtually anyone working with rubbers knew in 1986 that rubber got less rubbery (or resilient) as it was cooled, and therefore less likely to form a seal if used as an O-ring. The present author, as an employee of the UK company Laporte 1976-1980, knew that the rubber in ski boots, subject in use to winter cooling, were made of expensive synthetic polyurethanes so as to ensure resilience that could not be provided by normal shoe rubber.

Brunel had been taken aback by the degradation of his leather in 1848. In contrast, the experts who had advised against the *Challenger* launch (and had been overruled) were not surprised when, 73 seconds from launch, a hydrogen-oxygen explosion sent the orbital vehicle hurtling away to crash into the ocean,[*] when any surviving crew would have died. O-ring failure had indeed occurred, and a flame from a rocket booster joint had penetrated the orbital vehicle's external fuel tank.

Because people were killed and because the ultimate responsibility lay with a public body, NASA, there was extensive official enquiry. The detail, with names of individuals opposing the launch and insisting on the launch, was published, and the disaster is used as a case study in ethics training [4]. One is still left asking, "How could individuals interact so badly that the launch was allowed to occur?" The obvious answers – fear arising from job insecurity, flawed exercise of authority to break preset mission rules – are uncomfortable ones.

Unilever's manganese catalyst 1994-1995

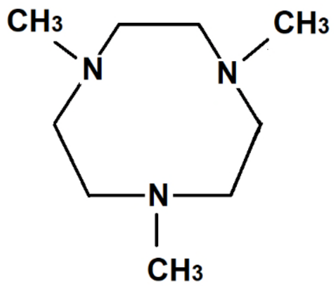
Another category (ii) failure, the "catalytic catastrophe" of the title of this article, occurred a quarter-century ago. No one was killed, some individuals may have had their clothes prematurely faded, and the failure affected mainly private companies, which suffered severe financial losses. Therefore, details such as are available for the *Challenger* disaster are not publicly available. Nevertheless, this failure is worthy of consideration because it may be closer to the personal experience of *Newsletter* readers. The product in question was PERSIL POWER, differing from products previously sold under the name PERSIL in containing *a manganese catalyst*.

The PERSIL POWER story is a particularly sad one, for PERSIL was the first outstandingly good domestic washing powder (launched in Germany in 1907 by the local company Henkel). The brand PERSIL was in 1927 territorially divided between Anglo-Dutch Unilever and Henkel (the former taking the UK, Ireland, and other territories, the latter taking Germany and other territories) [6] [7]. As we shall see, in UK and Ireland at least in 1994-5, the basic brand PERSIL lost reputation because of its use in the Unilever's disastrous product PERSIL POWER.

[*] Their only surprise was that the failure did not occur sooner after launch.

The original PERSIL of 1907 [8] contained a carboxylate soap made from natural fats, together with sodium perborate, sodium silicate, and sodium carbonate. The brand name PERSIL was derived from the first syllables of "*per*borate" and "*sil*icate". The perborate acted as a mild bleach (promoted in the UK in 1909 as the "Amazing Oxygen Washer" [9]), while the silicate facilitated the making of the composition into a powder. In subsequent decades, the formulation of washing powder was subject to many improvements, including the substitution of naturally-derived soaps by synthetic ones [10], but the essential idea of using a mild bleach remained unchanged, such as would remove stains while causing the colours of a garment to fade only slowly in repeated washes, acceptable relative to the expected lifetime of a garment.

The manganese catalyst in PERSIL POWER was advertised as an "accelerator" for the peroxygen bleach in the composition. The manganese was complexed, apparently recycling between the (IV) and (III) state without ceasing to be complexed (free aqueous manganese ions would have left brown manganese dioxide stains on the clothes) [11]-[13]. Unilever evidently persuaded *Nature* of the commercial and environmental importance of their researchers' work: a 3-page letter from them, with scientific embellishments such as EPR results, specified three of the complexing ligands they had worked with: 1,4,7-trimethyl-1,4,7-triazacyclononane –



– and two closely related compounds, also with 1,4,7-triazacyclononane rings.

Unilever's people did not disclose any actual washing powder compositions in their paper. Presumably by arrangement, Alan Comyns, writing in the same issue of *Nature* (23 June 1994), *did* identify the catalyst in PERSIL POWER with compounds containing such ligands. (Comyns was a consultant, with previous experience of detergent compositions at Laporte.)

So to the commercial disaster when PERSIL POWER was launched [13]-[17]:–
Unilever claimed that stains were removed faster and/or at lower temperatures. Procter & Gamble, Unilever's principal competitor, commissioned independent tests and made statements to the Dutch press about the damage to clothing resulting from use of PERSIL POWER. Unilever began an action in the Dutch Courts alleging that Procter & Gamble had made untruthful and misleading statements, but withdrew. Unilever conceded that repeated "abuse washing" of clean garments at temperatures exceeding 90 ^{o}C could cause damage. But pictures were published of viscose shirts which had lost most of their colour in 11 washes at 40 ^{o}C. Even after 5 washes, there was appreciable fading, but if the user thereafter switched to a conventional powder,

the accelerated fading continued, presumably because manganese from the earlier washes was retained on the fibres.

In response, Unilever reformulated PERSIL POWER with only one-fifth of the original amount of manganese catalyst. However, the product was soon withdrawn altogether. By the end of 1995, Unilever had formally written off £ 57 M of stocks of powder, while the Irish company Hickson, which had supplied the manganese catalyst, estimated that its profits had been reduced by £ 8 M as a result of the failure of PERSIL POWER. Much larger numbers for money wasted (development costs and marketing costs) are given by Childs, plausible in that these would not necessarily be separated out in company accounts. Other analysts estimated total losses at £ 250 M.

Unilever's chairman described the launch of PERSIL POWER as the worst marketing setback the group had ever experienced. By the use of the word "marketing", he was probably referring to diminished sales of regular PERSIL not containing the catalyst, whose reputation among consumers had been damaged by imperfect recollection, with a consequent decrease in Unilever's overall market share, and an increase in that of its competitor Procter & Gamble.

But the underlying *problem* was *not* in marketing: the Unilever chairman simultaneously announced that the company was reviewing the entire company process from research to innovation,[+] an admission, in the author's terms, that *a technological failure in category (ii)* had occurred. This technical problem was foreseen by Procter & Gamble, who warned Unilever before launch that PERSIL POWER was unsuitable for domestic use. Unilever's scientists must have been experienced in simulating domestic use of products, including by consumers who failed to observe instructions or warnings on the pack. So why was the risk not identified – and if it was, why were the results not taken account of? This may never be known, and in particular whether dysfunctional relationships as in the *Challenger* case were involved. The author's first-hand experience suggests two additional, less extreme possibilities. Firstly, people can focus narrowly on specific problems allocated to them in projects, and tend not to interfere when colleagues are failing in their own tasks. Secondly, once substantial money has been spent, managers are reluctant to admit that it has been wasted and to advise that good money should not be thrown after bad. In contrast, that is exactly the reluctance that Brunel overcame in June 1848 when he realised that his leather valves could not be economically remedied. *He* knew better than to proceed from a category (i) failure to a category (ii) failure.

General notes

(A) PERSIL is a registered trade mark of Unilever in some territories, and of Henkel in others.

[+] In "strategy-speak" as used by chairmen and others, "innovation" had – and still has – a narrow meaning: the first successful intrusion into the "real world" of a new concept (with business, economic, and/or social benefits).

(B) PERSIL POWER is a registered trade mark of Unilever. Henkel were unconnected with the product.

(C) The PERSIL POWER mark has been used within the last 5 years by Unilever in the forms Persil POWERGEMS and Persil POWERCAPS. These products are unrelated technically to PERSIL POWER as launched in 1994.

(D) The references to *two* ex-Laporte employees in this article have a non-coincidental connection. Laporte was the principal UK manufacturer of hydrogen peroxide, which was used on-site to make peroxygen compounds for detergents and also ε-caprolactone, ultimately incorporated in polyurethanes for ski boots.

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2. L. A. B. Pilkington, “Review lecture – the float glass process”, *Proc. Roy. Soc. London*, Ser. A., 1969, **314**, 1-25. The author, Sir Alastair Pilkington, despite his surname, was not a member of the family which founded the company.

3. Richard P Feynman, *What to you care what other people think?* (London: Unwin Hyman 1989), 113-237. This describes Feynman’s participation in the Presidential Commission enquiring into the disaster. Feynman obtained, with some difficulty, a sample of O-ring and showed that, if put into iced drinking water, the necessary resilience was lost (151-153, compare 133-4).

4. Texas A & M University, Department of Philosophy and Department of Mechanical Engineering, “Engineering ethics – the space shuttle Challenger disaster”, undated http://ethics.tamu.edu/wp-content/uploads/sites/7/2017/04/Shuttle.pdf (accessed 29 November 2020). The disaster has been used as a case study for non-technical senior managers as well as for engineers.

5. Wikipedia, “Space Shuttle *Challenger* disaster”, https://en.wikipedia.org/wiki/Space_Shuttle_Challenger_disaster, accessed 1 December 2020. This gives many further references.

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8. Ben Selinger, *Chemistry in the marketplace* (Crows Nest, NSW: Allen and Unwin, 5th edition 1998), 43-44.

9. Unilever, “Persil”, https://www.unilever.co.uk/brands/home-care/persil.html, accessed 1 December 2020.

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17. Evan Harold Davis, "How Unilever, Coke and the Mini car got it so wrong", 8 May 2011, https://www.bbc.co.uk/news/mobile/business-13285504, accessed 1 December 2020. This previews a BBC2 programme *Business nightmares – doomed designs*, broadcast 9 May 2011.

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