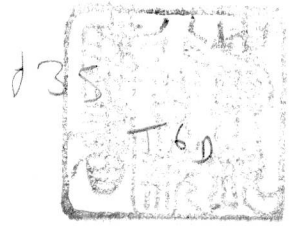


DEWPOINT CORROSION

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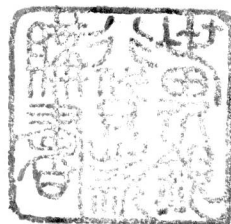
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Preface

This book, the first in the field to deal exclusively with the subject of dewpoint corrosion and its prevention, at a professional engineering level, contains the contributions prepared for an international conference on Dewpoint Corrosion: New Penalties – New Solutions (London, May 29–30, 1985).

The conference (Event No. 140 of the European Corrosion Federation) was organized by the London Branch of the Institution of Corrosion Science and Technology, in association with the CAPCIS/UMIST Dewpoint Corrosion Project,[†] the Institution of Chemical Engineers and the Society of Chemical Industry.

The proposal to hold the conference came from the members of the Dewpoint Corrosion Project, so it is worth recalling briefly the origins and objectives of this project. Towards the end of the 1970s, a decade in which oil prices increased by a factor of seven, the Department of Trade and Industry joined with some far-sighted UK organizations in a collaborative research project at the Corrosion and Protection Centre Industrial Services at the University of Manchester Institute of Science and Technology with the following objectives:

Understanding the mechanism and rate-determining step in dewpoint corrosion.

Selection and development of alloys and coatings with significantly lower corrosion rates than mild steels.

Development of monitoring techniques to provide on-line measurements of corrosion rates in operating plants.

Exploitation of the results to give increases in heat recovery and combustion efficiency and reductions in materials replacement and maintenance costs.

[†]The CAPCIS/UMIST Dewpoint Corrosion Project is supported by:
Department of Trade and Industry
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Esso Engineering (Europe) Ltd
Central Electricity Generating Board

The chapters in this book written by the members of the project cover all aspects of the work in pursuit of these objectives, for both large and small coal- and oil-fired plant. They are admirably complemented by the chapters commissioned from European and United States experts in the related fields of dewpoint corrosion in fully condensing domestic and district heating systems, in gas turbine and automobile exhaust systems and in flue gas desulphurization plant. The scope and subject of the contributions to this book are therefore wide and varied, but the emphasis throughout is on the provision of practical solutions to the problems arising from the condensation and corrosion processes. This practical approach is supplemented by a significant review of our current understanding of the mechanism of dewpoint corrosion.

I therefore hope that this book will prove both interesting and useful to its readers and, by filling a significant gap in the literature, help them to achieve the economies in resources that were the objective of the project.

I am grateful to the authors for sparing time from their many commitments to contribute to the book and especially to Drs Cox and Meadowcroft and the other members of the Dewpoint Corrosion Project for help and editorial advice. It is also a pleasure to acknowledge the enthusiastic help received from the staff of Ellis Horwood Ltd at Chichester, the Institution's publishers.

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May 1985

Introduction: Dewpoint corrosion – costs and potential savings

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ABSTRACT

This introductory chapter presents tentative estimates of the potential revenue cost savings to be obtained in three major UK fuel-burning sectors if dewpoint corrosion could be reduced sufficiently to allow operation with exit flue gas temperatures well below the dewpoint temperatures.

It is concluded that in the two sectors using very clean fuels, transport and natural gas space and water heating, materials and engineering solutions described in later chapters in this book show promise of realizing the estimated savings of £300–400 M pa. In the third sector, power generation, with its current use of cheap unrefined fuels, other factors may prevent substantial reductions of exit flue gas temperatures and the achievement of consequent higher efficiencies and cost savings.

Savings in environmental corrosion costs due to the trapping of the readily condensable acidic species in more efficient combustion plant with lower exit flue gas temperatures are more difficult to estimate but appear to be significantly less, probably by at least a factor of 10.

1. INTRODUCTION

Plant engineers and managers may be forgiven for wondering why we study dewpoint corrosion at all, and why we should hold a conference on the subject. Dewpoint corrosion in combustion plant is both insidious and pervasive but seldom causes costly dramatic failures, so from the 1950s until recent times

there has been little research on materials and methods to combat it. I shall attempt to show in this introduction that the present-day direct and indirect costs of dewpoint corrosion are very high and that the potential savings from mitigating its effects exceed, by orders of magnitude, the costs of the research in progress to do this. In the UK the latter probably lie in the range £0.3–3.0 M pa.

Basically dewpoint corrosion occurs when a gas is cooled below the saturation temperature appropriate to the concentration of the condensible corrosive species it contains. With gases containing several components, as do the waste flue gases resulting from combustion processes, there may be several dewpoint temperatures as the various species condense. Depending on the corrosivity of the liquid phases formed for the surfaces on which they condense, there will be corrosion rate peaks associated with the condensation processes as may be seen in Fig. 2 of Chapter 9 which is for a typical flue gas condensing on mild steel. In simple cases where no protective corrosion product is formed, condensation and corrosion rates may be directly related, and this and other more complex mechanisms of dewpoint corrosion are discussed in Chapters 2 and 9 by Cox and Meadowcroft and Jansen and Eenholt.

2. POTENTIAL SAVINGS IN THE PRINCIPAL FUEL-USING INDUSTRIES

Morris (1982), in his review of factors influencing dewpoint corrosion in power-generation plant, has shown that for the SO_3 concentrations in typical flue gases from the combustion of UK coals, dewpoint temperatures are in the range 100–140°C. If substantial areas of carbon steel plant (e.g. ducts, stack linings, air heaters etc.) were operated below this temperature range, corrosion rates in the range 0.1–5.0 mm/yr would occur (Morris, 1982). To avoid this potentially expensive situation power-generation plant (without flue gas cleaning equipment) is invariably operated so that the exit flue gases are not cooled below their dewpoint temperature — in the classic phrase: ‘the dewpoint is pushed out of the end of the stack’. But this operational solution, which is applied not only for corrosion reasons, has expensive consequences in heat losses. In fact it has been estimated (Holmes, 1983) that a 20°C reduction in exit gas temperature from the final heat recovery plant could provide an additional 0.32 percentage points in generation efficiency (35 → 35.32%). If this could be obtained over the whole coal burn of 80 M tonne pa in UK power stations savings to the consumer (or the Exchequer!) of about 0.7 M tonne or £30 M pa would result; clearly additional capital expenditure on corrosion-resistant materials and heat exchangers would be required. Even more efficient back-end heat exchangers are feasible in principle with the flue gas exit temperatures down to 50–60°C and correspondingly greater savings, but difficulties with plume rise and ash blockage of heat exchangers would probably be encountered.

Perhaps British Gas and the domestic boiler manufacturers are pointing the way forward in the field because Britton and Stevens in Chapter 10 and Kobussen from Holland in Chapter 11 show they are developing boiler designs and heat exchanger materials which will allow exit flue gas temperatures in the range 50–80°C with condensation of all the acidic products. For British Gas

and/or the consumer this could provide an increase in combustion efficiency of some 10 percentage points for domestic central heating boilers (85 → 95%). Gas consumption in such boilers in the UK is about 6000 M therms pa at a current price of 37 p/therm. If the projected increase in efficiency could be achieved over this entire heating load, savings of 600 M therms or £200 M pa would, in principle be possible. Again there may be additional capital costs in the construction of the boiler for larger heat exchangers and more corrosion-resistant materials.

Comparable but smaller savings may also be feasible in domestic and industrial oil-fired heating plant but these cannot be quantified so readily because of the diversity of the plant and its applications.

The other major fuel using industry in the UK is, of course, transport; but with most internal combustion engines the exhaust gases are frequently cooled below their dewpoint temperature, at least during the cold start part of their operating cycle. The dire consequences and costs arising from exhaust system corrosion and failure caused by the acid condensate are already too familiar to all motorists. Exhaust replacement costs are currently in the range £200–300 M pa and this figure could probably be cut by 40–50% by the use of more expensive but more resistant materials and the engineering solutions discussed later in this book (Cannings, Chapter 14; Boden and Harris, Chapter 15). Some consideration also needs to be given to possible increases in engine efficiency which might be realizable from the use of fully condensing exhaust systems.

To summarize this section on potential revenue savings in the three major fuel-using sectors in the UK, it appears that on preliminary estimates these could amount to about £400 M pa in materials and fuel costs, provided that secondary problems with plume rise and disposal of waste products can also be solved.

3. SECONDARY COSTS ASSOCIATED WITH DEWPOINT CORROSION

In section 1 we pointed out that the current method of avoiding the adverse effects of dewpoint corrosion in combustion plant and appliances was to ensure that the flue exhaust gases were emitted at temperatures exceeding the dewpoints of the acidic combustion products. Thus the potentially corrosive liquid phases are effectively removed from the operators' plant as gases and released to the environment, but at the expense of the increased fuel costs discussed in section 2. It is instructive to attempt to estimate, however roughly, the cost to the UK economy of the corrosion due to the emitted products. I must emphasize that this is a very different calculation from those attempted earlier (OECD, 1981) in which the total costs of corrosion due to emitted sulphur oxide products were estimated. Here we are only concerned with the corrosion caused by the readily condensible combustion products, that is those constituents of the flue gas (SO_3 and HCl) which would be retained in the plant if materials and engineering solutions allowed operation below their dewpoint temperature. For power stations burning coal containing 0.3 wt% Cl and 1.5 wt% S on average (values derived from Cutler *et al.* (1983) and Clarke & Morris (1983)) the flue gas emitted with current operating conditions contains about 200 vppm HCl and

1200 vppm sulphur oxides of which about 5 vppm would be SO_3 . With operation well below the dewpoint temperature range it might be possible to remove all the SO_3 and some of the HCl (although complete removal of the latter would require exit temperatures as low as 40–50°C).

The cost of the corrosion damage to zinc-coated and painted steel due to emitted sulphur oxides has been estimated on various simplifying assumptions (OECD, 1981) for 12 European countries including the UK. Tables given there imply 1985 costs of about £2000 M pa for the UK and suggest that reducing the total UK sulphur oxide emissions from 5.2 Mt to 3.4 Mt pa as in Scenario 3 in the Tables might give savings of £150 M pa. Thus the maximum anticipated reduction of about 0.02 Mt pa in sulphur oxides emission from coal-fired power stations would produce relatively negligible savings in environmental corrosion costs of £1–2 M pa. Even these small savings may not be realized in practice because the SO_3 would be rapidly removed in the vicinity of the power stations which nowadays tend to be located in rural or coastal environments away from buildings. Greater, but still trivial savings of up to £3 M pa in the total cost of £2000 M pa, would result from reductions in sulphur oxides emissions associated with the reduction in fuel burn due to increased efficiency, especially if this could be obtained over all the UK's combustion plant, domestic and industrial.

Further savings would be possible if the exit gas temperatures in power stations and other plants could be lowered sufficiently to remove the HCl. Combustion of a coal containing 0.3% Cl will produce concentrations of about 35 g/m³ HCl in the air at the point where the plume reaches ground level, assuming a dilution factor of 10^4 (Ross & Shaw, 1982). During periods of rain, much of this acid will be washed out close to the source as will the SO_3 and so will produce disproportionately small overall corrosive effects. For this and other reasons, it is difficult to arrive at an accurate assessment of the saving to be expected from trapping the HCl.

No reliable dose–response relations are available for the effect of chloride on the corrosion of zinc-coated and painted steel. Results from the British Iron and Steel Research Association laboratories (Hudson & Stanners, 1953) showed a surprisingly small difference in rates of corrosion between rural and marine sites and areas such as Woolwich and Sheffield which were heavily polluted with both HCl and SO_2 , although the corrosion effects may have been perturbed by the large variations in rainfall between the exposure sites. Mikhailovskii *et al.* (1980) have provided corrosion rate dependences on SO_2 and Cl^- concentrations (measured by atmospheric gauges) which make it possible to calculate 'initial' rates of corrosion given sufficient meteorological data. These show that other things (humidity, temperature etc.) being equal, chloride should be three times more corrosive than SO_2 . This may not be relevant in British conditions, where the moisture film on the specimen is seldom frozen at the times of greatest pollution and the proportions of soluble chlorine and sulphur species may be different.

An approximate estimate of the saving to be expected from eliminating the HCl from UK power station emissions can be obtained from the OECD cost–benefit calculation with the conservative assumptions that HCl and SO_2 are distributed in the same way and produce the same corrosive effect concentration

for concentration. In this case, the saving would be £28 M pa (or three times this figure if Mikhailovskii's data were applicable to British conditions).

This calculation is highly unreliable, and probably overestimates the total revenue savings from mitigating metallic corrosion, because, particularly in times of rain, the corrosion would be concentrated in the immediate vicinity of the power stations. There would of course be additional capital costs for corrosion-resistant materials for ducting and heat-exchangers, which might, however, be offset by the increase in thermal efficiency. Other possible financial benefits may also arise from reduction of damage to non-metallic building materials and improved welfare of humans, livestock and crops currently exposed to slightly enhanced HCl and sulphur oxide concentrations.

4. CONCLUSIONS

Very approximate estimates have been given of potential savings to be made through conquering or alleviating the effects of dewpoint corrosion.

It is concluded that the greatest potential revenue savings, perhaps amounting to £400 M pa, are in the major fuel-using industries of electric power generation, gas-fired space and hot water heating, and transport. In the first two of these the savings would arise from the more efficient utilization of fuel in wholly or partly condensing boilers while in the third, transport, materials and labour costs would provide the main savings.

Smaller savings (perhaps by a factor of 10–20) in environmental corrosion costs would result from the reduction of emissions from UK power stations and other combustion plant by removal of the condensable species ($\text{SO}_3/\text{H}_2\text{O}$ and HCl).

The total potential annual revenue savings exceed current UK research costs by a factor of about 100.

The feasibility and capital costs of implementing the changes proposed have not been considered in this introduction but later chapters in this book will show that in two of the three fuel-using industries the research in progress bears promise of achieving the projected savings. In the third, power generation, problems not directly associated with dewpoint corrosion may prevent operation with exit flue gas temperatures below the dewpoint.

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