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Removal of Flue Gas Tunnels Solves Problems

A brief report on an ammonia plant reformer operations problems caused by frequent breakdowns in flue gas tunnels in an English processing plant.

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A problem of frequent shutdowns for repairs on primary reformers on three ammonia plants at Imperial Chemical Industries' Billingham works was solved by removing the flue gas tunnels.

The reformers were originally designed with tunnels to evacuate the combustion gases through the flue gas ducts and thence into the convection banks. The tunnels did not and do not have tunnel burners, unlike many other Kellogg reformers.

A considerable number of wall and roof collapses on the No. 1 Plant reformer between 1970 and 1972 severely damaged its tunnels, and the plant successfully operated with damaged tunnels for many months. When it was eventually shut down for a major overhaul in September 1972, the length of the shutdown was reduced by removing the tunnels and replacing them with a short Corbel design. This action was supported at the time by the operating experience with damaged tunnels and by mathematical analysis of the reformer combustion gas flow. Later operating experience and further, more detailed analysis supported the correctness of the action.

Tube flux surveys before and after removal of the tunnel showed no significant differences, with the maximum tube heat fluxes still occurring at a relative depth of 0.3.

Noise problem also was solved

Following the tunnels removal there was a problem with humming in the reformer. It was found to be due to an acoustic change in the reformer. However, this change was eventually shown to be caused primarily by the renewal of the reformer walls and roof and not by the removal of the tunnels. The sound was eliminated by an adjustment to position of the burner tip.

The tunnels on Nos. 2 and 3 Plants have since also been removed.

In the original design, the primary reformers at Billingham had seven rows of 28 tubes each. The tubes are spaced between eight rows of 20 burners each.

The reformer as designed by Kellogg was equipped with two features designed to create uniformity of flow of the combustion gases through it. These were the combustion air inlet dampers and the flue gas tunnels.

Ideally, the temperature profile of each tube in the reformer should be identical. The source of the heat is the burners. Therefore, to achieve this uniformity, the air and fuel flow rates should be uniform across the furnace, giving parallel vertical stream lines. Figure 1 shows this ideal situation. Note the absence of tunnel burners.

Because of the practical requirements of design the flue gas leaves the furnace at its bottom north side only. This means that if the flow rates of gas along routes *ACE* and *ABDFE* in Figure 1 are to be the same, then the pressure drop' along these routes must be the same. If the dampers and tunnels were absent, the pressure drop along *ACE* being

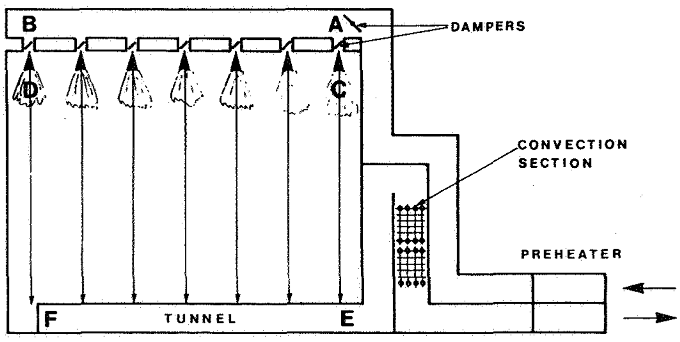


Figure 1. Diagram of the reformer, showing the combustion air and flue gas tunnels.

equal to that along *ABDFE*, a higher flow rate would result along *ACE*.

The dampers and tunnels introduce a restriction to flow along *ACE* relative to *BDF*, allowing uniformity of combustion gases to be achieved. That, at least, was the original philosophy.

Figures 2 and 3 show the original tunnel design, which had walls of a single thickness of brick with single-slab flat roofs.

In service, the tunnels were insufficiently robust and were continually being damaged. The flat slab roof was particularly susceptible to damage.

A common cause of damage was the bricks suspended from metal hangers. The hangers would fail due to overheating by combustion gas seeping through the spaces between the bricks. This roof design has since been replaced by a monolithic concrete roof which does not suffer the same problem. The falling bricks would smash the flat slabs on the roof of the tunnels, which were often in poor condition due to thermal cycling.

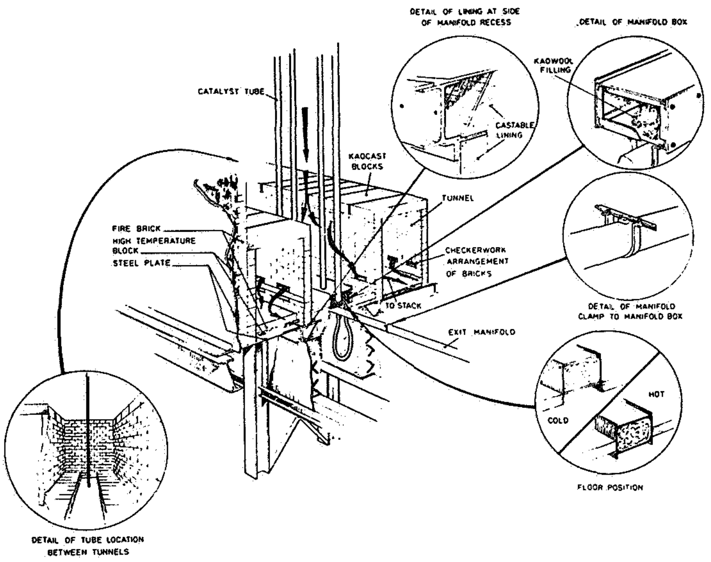


Figure 2. Isometric of the original design of the flue gas tunnels.

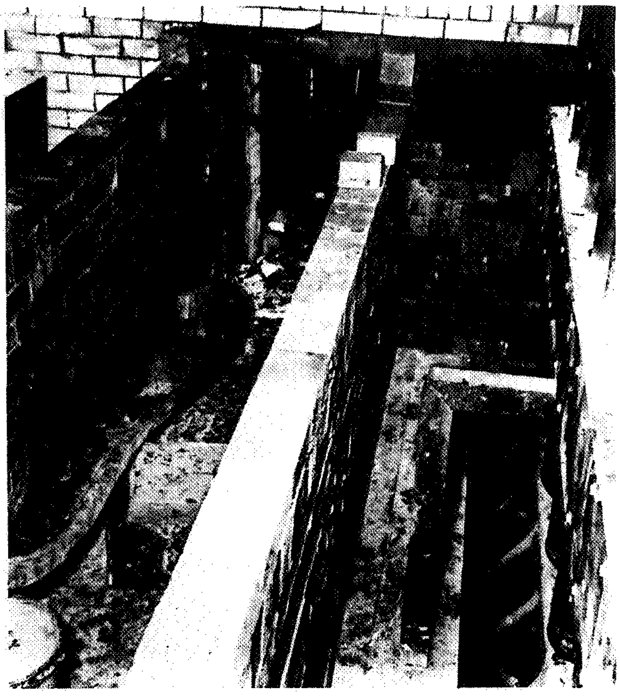


Figure 3. Photograph of the original flue gas tunnel.

The design of the tunnels was modified several times in their life to improve the reformer temperature distribution and reduce the incidence of tube coking when the plants were running on naphtha feed. With the conversion of the plants to natural gas in the 1970/71 period, tube coking was eliminated as a problem.

Maintenance of the tunnels was a problem for two reasons. Firstly, because they suffered damage they needed repair. This work could either be carried out before or after other maintenance activities inside the reformer but rarely concurrently. It thus extended the length of the critical path of the reformer repair work during a shutdown.

Secondly, the very presence of the tunnels meant that the entire floor of the reformer needed to be staged out before work could start inside on walls, roof, or tubes. This again was always a critical path job.

Tunnels removed from the first reformer

The major overhaul of No. 1 Plant planned for September 1972 was identified as having a long reformer critical path. Two years earlier, the reformer had suffered a short period of excessively high temperatures. That had led to an abnormal number of thermal cycles, causing extensive roof and wall damage and an abnormally high number of tube failures. The collapse of the roof had severely damaged the tunnels. The result of all this damage was an exceedingly long critical path on the reformer repair work.

As always, the pressure to minimize the shutdown length was great. Thus, the proposal was made to remove the tunnels and thereby save time and money in the shutdown.

The decision was taken to remove the tunnels, and the support for that decision was based on the following points:

Mathematical analysis. Analysis of the flow pattern in this reformer was carried out by the division research department. Their conclusion was that with the tunnels removed, the combustion air supply could, in principle, be controlled by the inlet dampers to maintain uniformity without incurring significant pressure losses.

To avoid high tube skin temperatures at the bottom of the tubes adjacent to the flue openings due to local high gas velocities, a short Corbel design tunnel was adopted. It is shown in Figures 4 and 5.

The effect of the removal of the tunnels on temperature distribution across the bottom of the furnace was considered. It was shown that the dominance of radiation heat transfer over convection is so great that the temperature distribution will remain reasonably unifrom even if the stream lines deviate significantly from the vertical; the tendency for that to occur is resisted by the buoyancy effects.

A detailed numerical analysis of the reformer flow was carried out; and some results are presented here. Figures 6 and 7 compare the stream lines with and without tunnels respectively. Figures 8 and 9 compare the tube wall temperatures with and without the tunnels. The effect on temperature

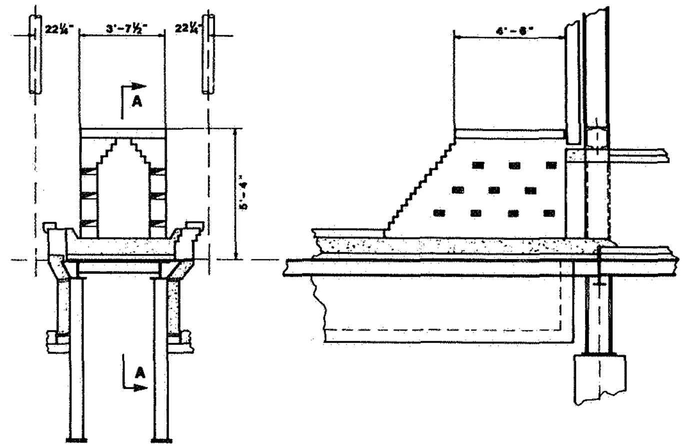


Figure 4. The modified corbel flue gas tunnel.

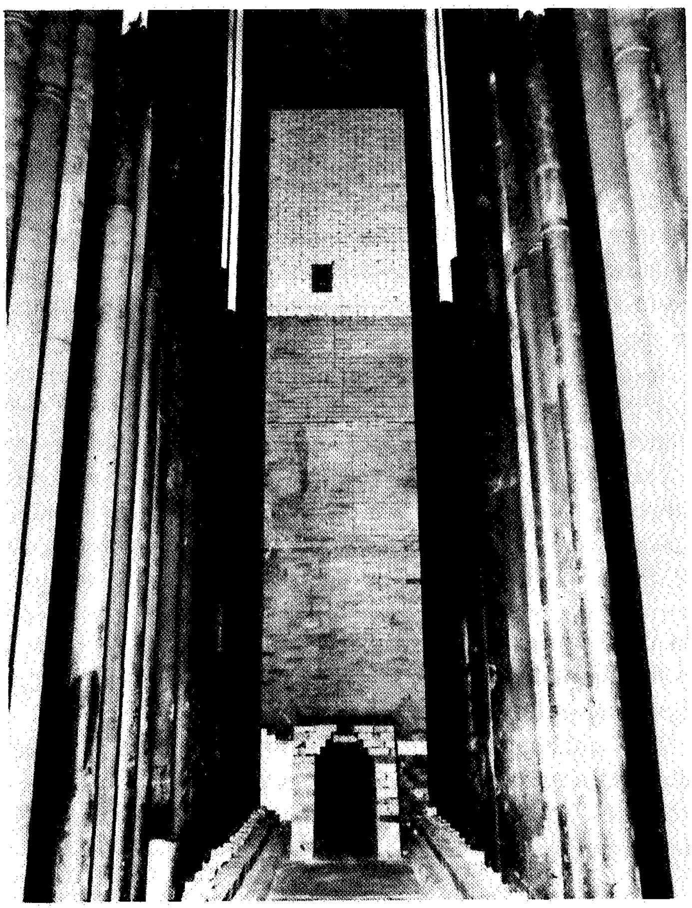


Figure 5. Photograph of the modified flue gas tunnel.

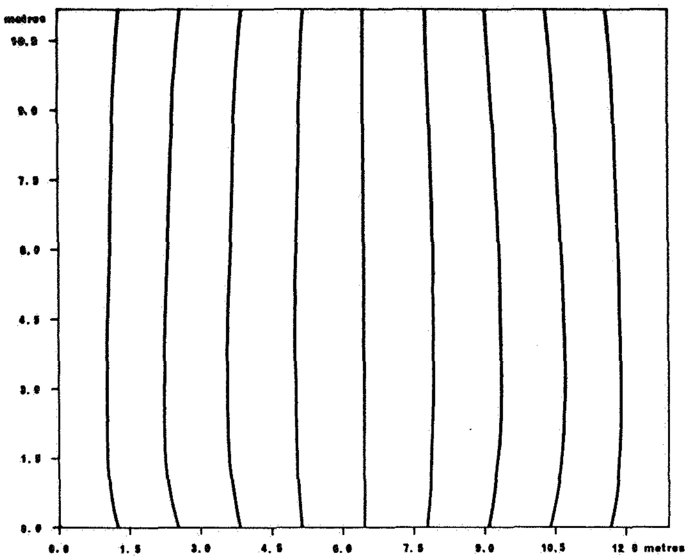


Figure 6. Computer analysis results, showing the stream function for the reformer with the original tunnels.

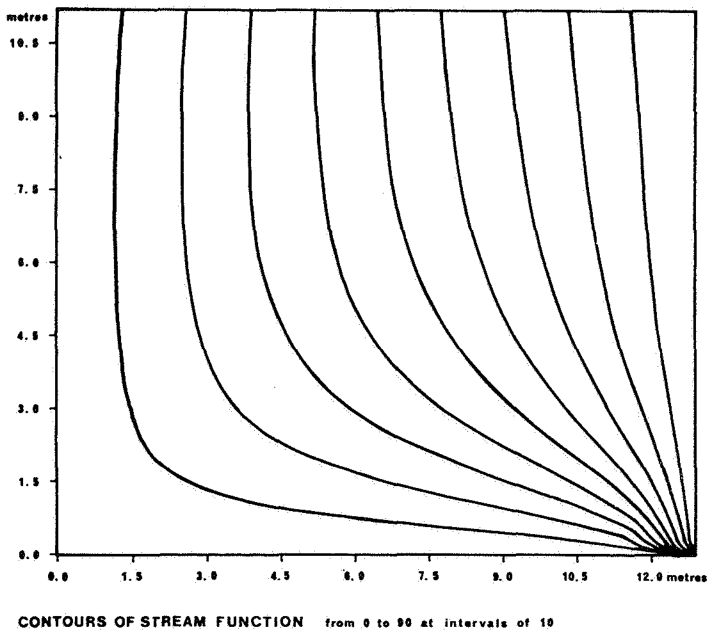


Figure 7. Computer analysis results showing the stream function for the reformer without the original tunnels.

is predicted to raise the temperature at point *A* from 740° to 760°C and to lower it at *B* from 740° to 700°C.

These changes in tube wall temperature do not, however, approach the temperature limit for the tubes because the top-fired furnace has maximum temperatures at a relative depth of 0.3 from the top.

Practical experiences. The reformers had been operating for varying periods of time with the tunnels in various states of collapse. At no time had any operating problems been experienced with the reformers. Thus the decision was taken to remove the tunnels and replace them with the short Corbel design.

Comparing results before and after change

There have been no operation problems with the reformers due to removal of the tunnels. The tunnels were removed

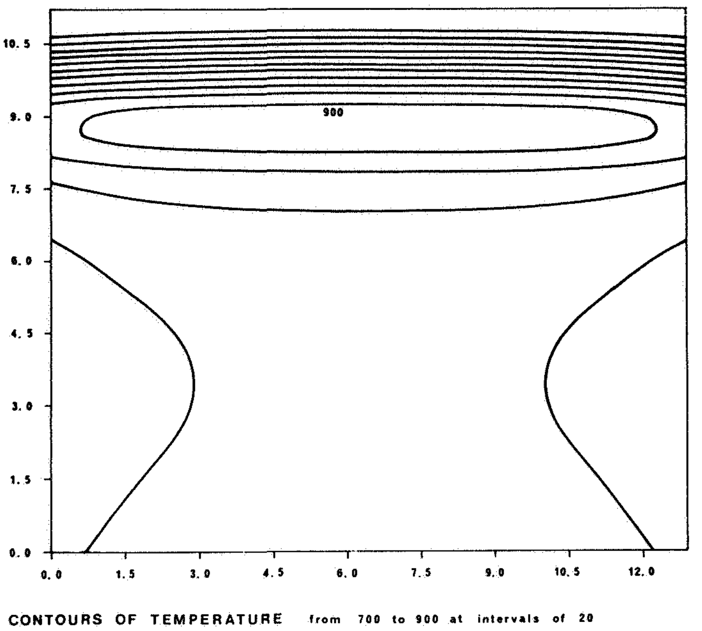


Figure 8. Computer analysis results showing tube wall temperatures with the original tunnels.

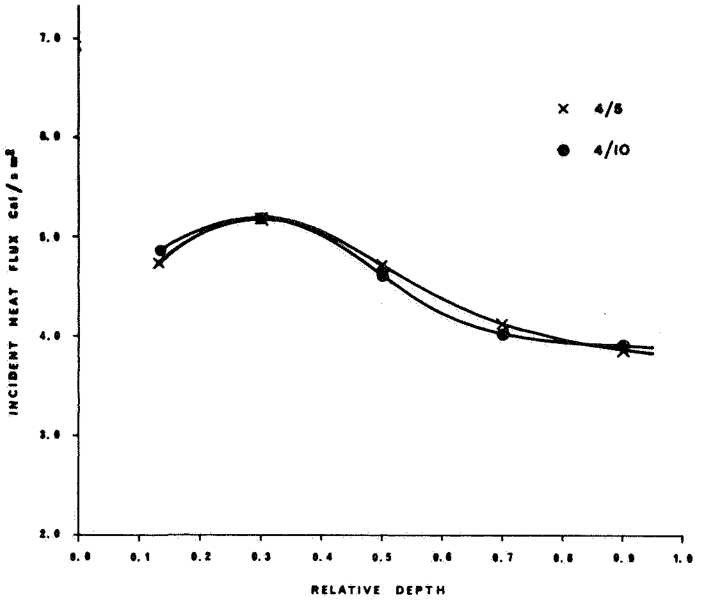


Figure 10. Tube flux profile for Row 4, Tubes 5 and 10, of the unmodified reformer.

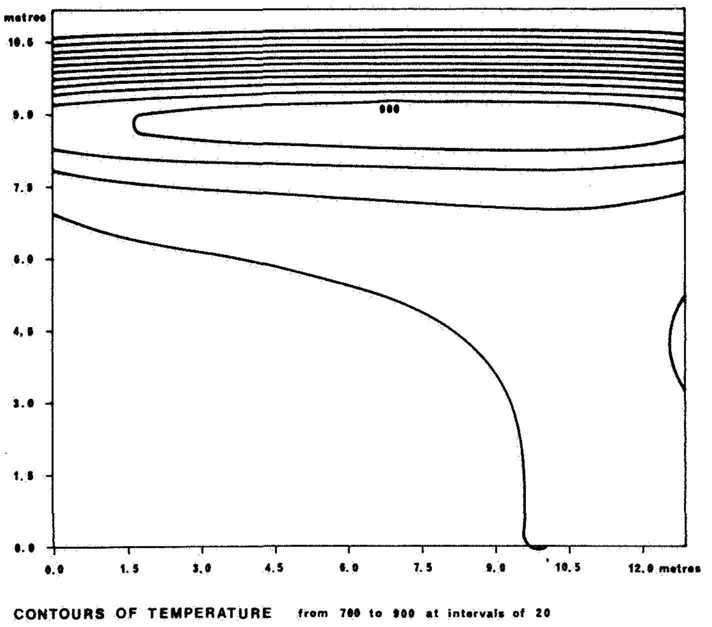


Figure 9. Computer analysis results showing tube wall temperatures without the original tunnels.

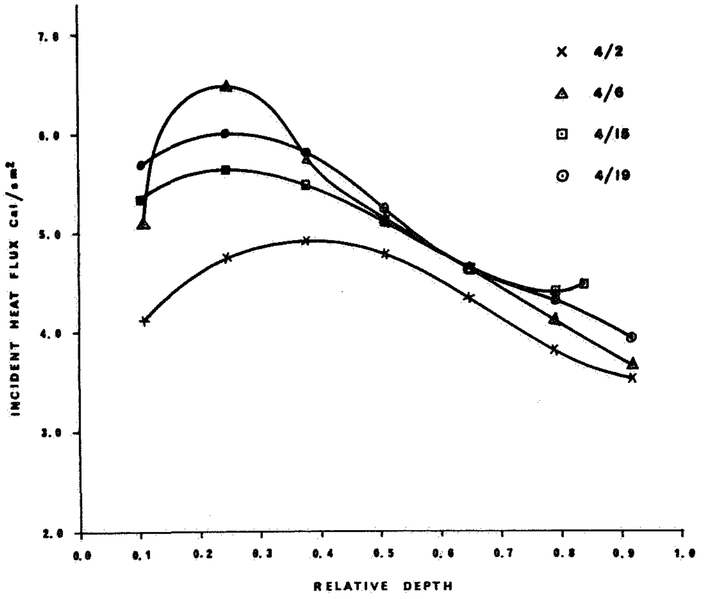


Figure 11. Tube flux profile for Row 4, Tubes 2, 6, 15, and 19 of the modified reformer.

from the other two Plants in April, 1974, and October, 1975, respectively.

Tube wall temperature surveys carried out by optical pyrometer on the No. 1 Plant reformer revealed no statistically significant differences. Two series of heat flux profiles had been carried out on the No. 1 Plant reformer prior to the tunnels removal: these were repeated after the removal. Some comparative results are shown in Figures 10 and 11. The only two things to note from these surveys were: 1) the tube bottom temperatures were never anywhere near the tube maximum temperatures: and 2) after the removal of the tunnels, the temperatures of the tube bottoms nearer to the flue openings were higher than that of those further away.

Thus, in the Billingham Kellogg top-fired furnaces on natural gas feed, the use of tunnels for the flue gas could appear to be superfluous in that any beneficial effect that they have is masked by other variables of air supply or fuel burning.

One problem was encountered on recommissioning the No. 1 Plant reformer after the tunnels were removed. This was a noise problem. The reformer was vibrating at 66 cycles/sec. with sufficient amplitude to be damaging. It was a case reformer "screaming," i.e., the noise of combustion was exciting the natural frequency of the combustion chamber.

It was thought at first that the natural frequency of the reformer had been changed by the removal of the tunnels. In fact, changes to the acoustic properties of the reformer caused by new walls and roof and a raising of the gas temperature due to reduced air leakage through these new surfaces offset any change due to the removal of the tunnels.

The noise problem was solved by lowering the burner top relative to the swirler by ¾in., as shown in Figure 12. #

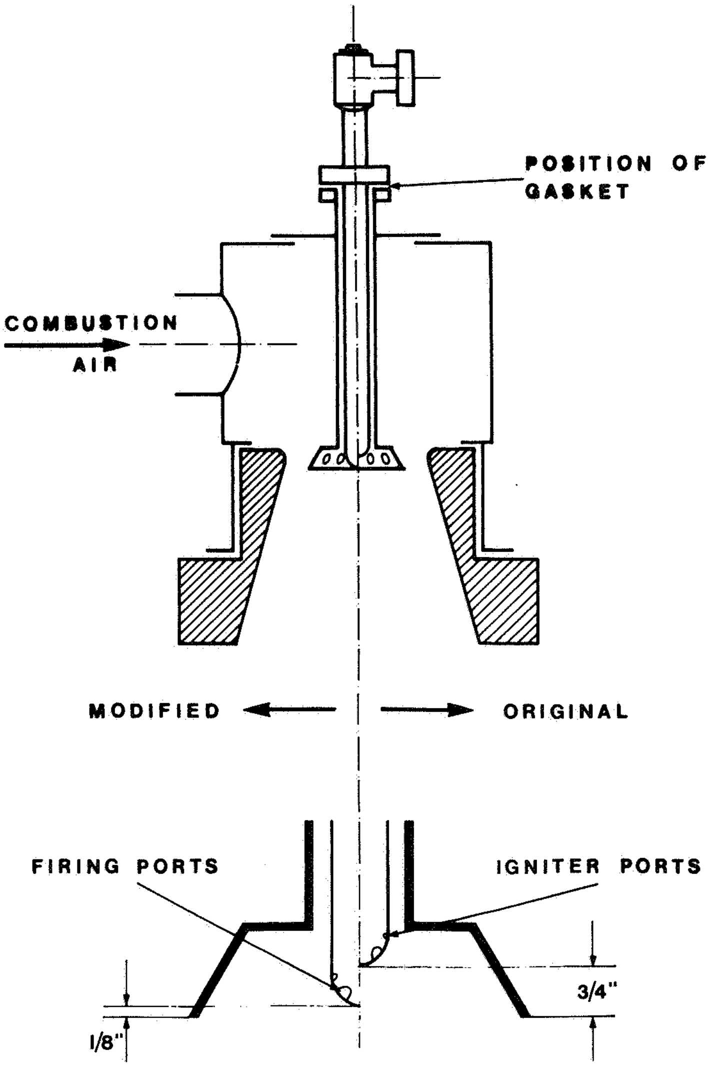
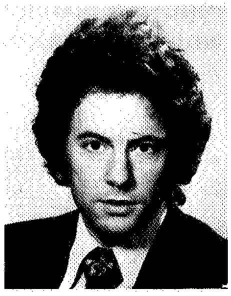


Figure 12. The modification to the burners which prevented "screaming."



EDMONDSON, I. R.

DISCUSSION

JOHN LIVINGSTONE, ICI: I would just like to make one comment to what Dr. Edmondson has said. And that is that the difference between the furnaces and Billingham and the furnaces in most of the American plants is that they were designed for naphtha, and we do not have tunnel burners as you have. Those tunnels are purely and simply in that furnace, designed to distribute gas into the convection section of the flue gas system, and therefore there's no question of burning tunnel burners into an open furnace.

But nevertheless everything that Dr. Edmondson has said has been borne out in practice and there has been no discernible change in thermal efficiency of the box. The removal of the tunnels has meant for most of our turnarounds, a two to three day reduction in terms of the time involved in doing maintenance work inside the box.

JOHN BLANKEN, UKF-Holland: Could you be slightly more specific about your difference in temperature between the outlets of the catalyst tubes? After we have an Incoloy manifold failure we consider 10 degrees C difference between one side of the manifold and the other, significant. Would you consider that significant?

EDMONDSON: I think the answer is that we wouldn't consider it significant.

BLANKEN: You would not consider it significant?

EDMONDSON: Ten degrees C.

BLANKEN: That means on one side it is 810 degrees C. and on the other side 820.

EDMONDSON: It depends on your point of view. Purely in terms of metal temperatures and creep life of the local metal —no, it's not significant. Are you perhaps thinking of the differential expansion stresses on the header?

BLANKEN: The Incoloy 800 bottom manifold has failed in one of our plants and we did some investigation and we found that the lifetime is very much influenced by temperature.

EDMONDSON: We haven't had that problem in quite the same form. We don't have incoloy there. So I can say it does sound interesting but no, we don't consider it a problem.

LIVINGSTONE: Could I comment on that? I think there's a misapprehension here because taking the tunnels out has changed the contours of temperature in the enclosure, at the bottom of the tube, but that is only a small part of the tube. The gas temperature in the left hand end of the manifold is a function of the heat picked up in the whole way down. And only at bottom end, where there is least temperature difference between the process gas and the flue gas - there's maybe 20 degrees difference in driving force there between one side and the other.

But the average temperature difference of the gas reaching the bottom of the riser from the left and from the right, we would expect to be pretty small.

DICK DAZE, Heat Research: Before I ask my question I might mention that this reformer has outlet pigtails rather than a manifold which might have some bearing on the prior questions. But I'd like to make one or two comments. This reformer was one of the first of the new design for large tonnage ammonia plants. Over the years the tunnel design has been continuously improved, for example, the width of the brick, the thickness of the slabs, selection of materials, etc. have been significantly upgraded from a strength and operational viewpoint.

Our latest designs do not use arch bricks. - We are going to ceramic fiber insulation on the arch so a lot of the concerns of falling arch brick may not be applicable today as they were years ago. It is also important to note that the ICI Reformer has a forced draft design which allows you to provide some adjustment to flow distribution to the box by adjusting individual airflow to each burner as compared to a non-forced draft installation. The forced draft system provides ability to control flue gas flow and the resulting temperature profile. Also the tube length is a lot longer than other reformers designed originally for natural gas.

So with a longer tube length you probably have a lesser effect of maldistribution than if you had a very short box. These are some points that should be considered in the total picture.

EDMONDSON: Yes, I wouldn't disagree with anything there. Right. If we'd have had a better design to start with, we wouldn't have the problem maybe.

DAZE: Well the design has been evolutionary over the last ten or twelve years as a result of operating feedback.

JIM BROOKS, Agrico Chemical: This question of mine does not pertain to the removal of the tunnels but I believe in the third slide that you showed, I believe I detected some catalyst tubes that were insulated? If so, is this a standard practice?

EDMONDSON: It isn't a standard practice. Did anyone else see that? I don't think I did.

BROOKS: Is it standard practice to insulate?

EDMONDSON: As far as I was aware, there was no insulation on the catalyst tubes, and it isn't standard practice at ICI.

BROOKS: In Figure 5, the white tube - up toward the top. The top third, or maybe the top half of the tube. Are those tubes insulated?

EDMONDSON: No, that's not insulation. This is the completion of the shutdown when the new roof was put in. To be honest, I'm not sure what it is. I don't know whether John perhaps knows about that.

JOHN LIVINGSTONE, ICI: That was a white paint that was put on, a whitewash that was put on as a means of reducing radiant heat effects on the hot section of tubes. No insulation whatsoever on any of the tubes, other than, of course, the pigtails exit from the reformer which are insulated. That is a whitewash paint that was put on there to extend the life of the tubes by reducing radiant heat effects.

BROOKS: Sometime back we experienced some hot tubes in our furnace and I called several people throughout the country to see if it was customary to insulate the catalyst tubes, or what could we do to help us along without having a crash shutdown, you know, other corrective action that would require a shutdown. I just wondered if there is anybody in this audience that has insulated their tubes this way. When I first saw this, I thought well here is the answer to my question.

JAN BLANKEN, UKF-Holland: Last year Jansen of our company presented a paper in which he mentions the insulation of all welds of our reformer tubes. And I understand from the slides Allied Chemical presented, they are doing the same.

Now I am not saying that you should insulate furnace tubes because of hot spots, but if you want to do it, in last years' manual you can find how to do it.

Q: Did you have a waste heat boiler on the back of your reformer on the outlet?

EDMONDSON: A waste heat boiler.

Q: Yeah, your flue gas, did it go to a waste heat boiler?

EDMONDSON: Not waste heat boilers, no. Convection coils superheated and preheated.

Q: Was there any change on the operation of the flue gas, distribution through the tunnel?

EDMONDSON: No because once you get to that stage, then you've got a bulk mix of the combustion gases. No, certainly no change was detected.