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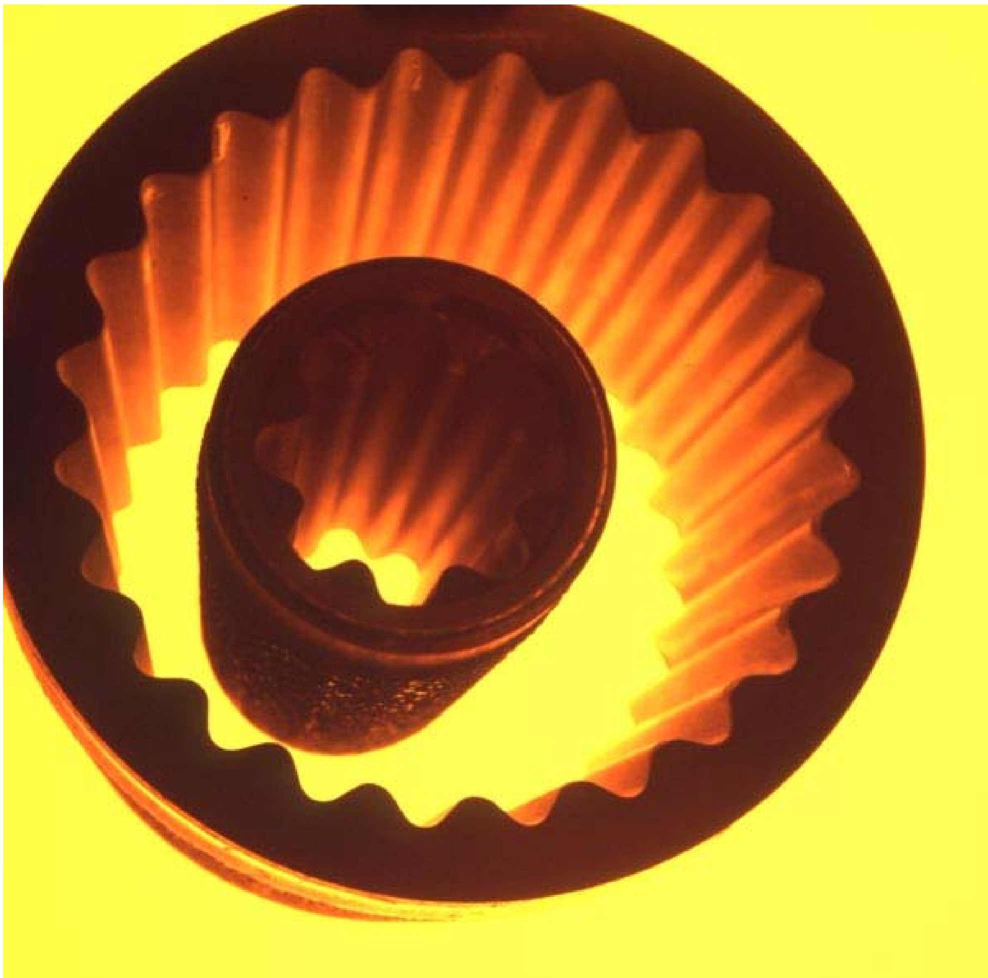
Potential economic benefits from Paralloy centrifugally cast, internally finned PEP Tube



Profile

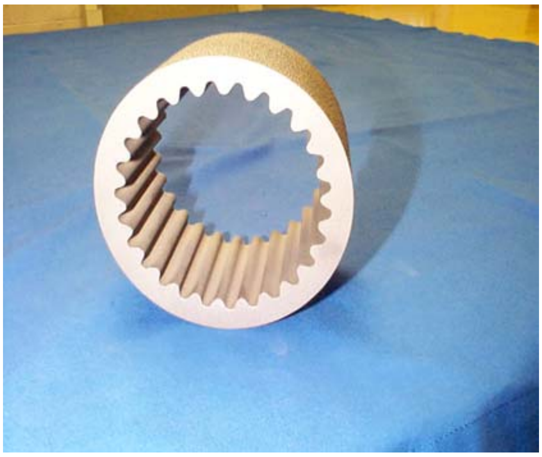
Derick Turner, a Chartered Mechanical Engineer, is engaged by Paralloy Ltd at Billingham as a Consultant. Previously he was employed for over 30 years by bp, the last 16 years as the Mechanical Engineer responsible for development and repair of the olefins hot side equipment at the Grangemouth site, specialising in work associated with pyrolysis furnaces. In this paper Derick evaluates the potential financial benefits of using internally finned cast alloy tubes.

Introduction

The historical development of ethylene and reformer furnace tubes over the last 30 years has been well documented, evolving from wrought tube to cast HK40, HPNb Mod then microalloy. The chemical industry believed that, with the development of the microalloy range of materials, the limit of what could be achieved by adjusting the chemical composition of the alloys was being approached. It was believed that future compositional changes would achieve only small operating temperature increases or increases in material properties. The use of ceramic coil material has, despite high development expenditure, failed to make an impact on coil design. While the material is suitable for very high temperature operation it has not been possible to find an effective joining technique. The technological breakthrough that the industry had been awaiting and looking for arrived with the development, by Paralloy, of a method of electrochemical removal of tube wall material from a centrifugally cast tube. This highly innovative technology produces a smooth internally profiled cast tube with a higher internal heat transfer surface area, than can be achieved using a plain bore tube.

The use of Paralloy **Ethylene Profiled (PEP)** straight finned cast tube should be viewed as a versatile, production increasing or cost saving tool in a furnace radiant retrofit, or as a design enhancing feature in new furnace design, allowing reduced radiant box size for a given rated production.

PEP vs wrought tube



The use of internally profiled tubes is not a new phenomenon, wrought tubes having been used for a number of years. These tubes attempted to compete with the cast tubes in terms of Cr/Ni content (25/20 and 25/35) providing carburisation resistance. However, where the high carbon content of the cast alloys provides the strengthening effect of secondary carbides in service, attempts to add additions to the wrought product to reproduce this benefit had the effect of reducing the creep strength of the material in comparison to cast tubes. This strength reduction had the detrimental effect of reducing the maximum operating tube metal temperature when using wrought radiant section tubes.

PEP profiled tube gives all of the high temperature benefits of high creep strength and carburisation resistance associated with the established high carbon cast alloys. Coupled with a high heat transfer surface to volume ratio PEP tube offers a unique opportunity to tune the furnace design and operation to increase financial return.

Advantages of PEP Tube replacing cast plain tube

The commercial advantages of utilising PEP tube should be carefully evaluated when considering a radiant section re-tube as the opportunities in terms of increased plant financial contribution to the business can have a considerable beneficial impact. Likewise when considering an expansion or a new furnace the use of PEP tube can have a considerable impact on the final results.

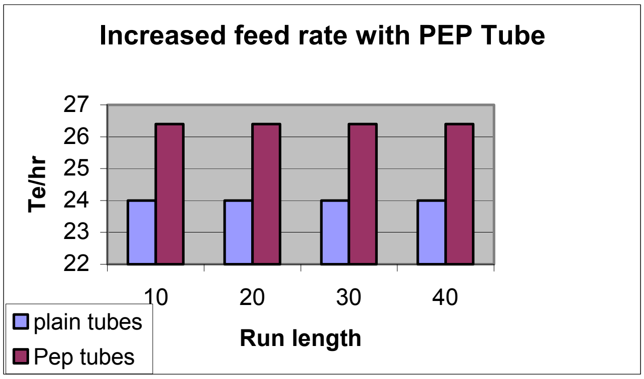
Furnace expansion

To increase production from an existing radiant box it is normally necessary to increase the amount of tube surface area available for heat transfer, cracking the additional feed to be processed. Different furnace designers have their unique methods for doing this and could include adding an additional row of tubes parallel to but offset to the existing tubes, lengthening the coil by the addition of a new trough in the floor of the hearth or by employing cranks and sweeps to the existing geometry. Paralloy's PEP tube provides an easily installed alternative to costly configuration or radiant box changes.

As part of a properly engineered furnace study the introduction of PEP Tube gives the potential to significantly increase furnace throughput or increase coil life depending on how the plant operator elects to operate the furnaces. The following sections of this report outline some of the alternative strategies and show some possible benefits that might be expected. The operating strategies chosen are increasing feed rate (a), reducing Tube Metal Temperatures (TMT) without changing feed rate (b) and running at existing feed rate and TMTs (c).

(a) Increasing feed rate

Fig 1 (Te/hr = Tonnes (1,000kg) per hour)



By utilising the increased heat transfer surface area available with PEP tube the plant operator can elect to run the furnace with TMTs comparable with those used with plain tubes, utilising the additional heat transfer available, increasing throughput. The maximum end of run temperatures would not differ from those used with plain tubes and are in the range 1080 – 1100º C depending on the material employed and the operating severity selected. Using this philosophy the increased energy can be harnessed and the coil can process around 10% additional total feed (see Fig 1). The percentage increase is dependant on the tube profile chosen. The additional feed can be 10% fresh feed or a combination of fresh and recycled feed dependent on the plant configuration and feed slate. CFD analysis has shown that the coil ΔP changes attributable to using PEP tube are insignificant (See Fig 2) and this has been proved to be the case in commercial operation. To maintain selectivity the tube profile cross sectional area should remain unchanged from that required for plain bore tube, as is the case with all tube bore modifications. To realise this benefit there must be no other process constraints that would limit full utilisation of the coil geometry.

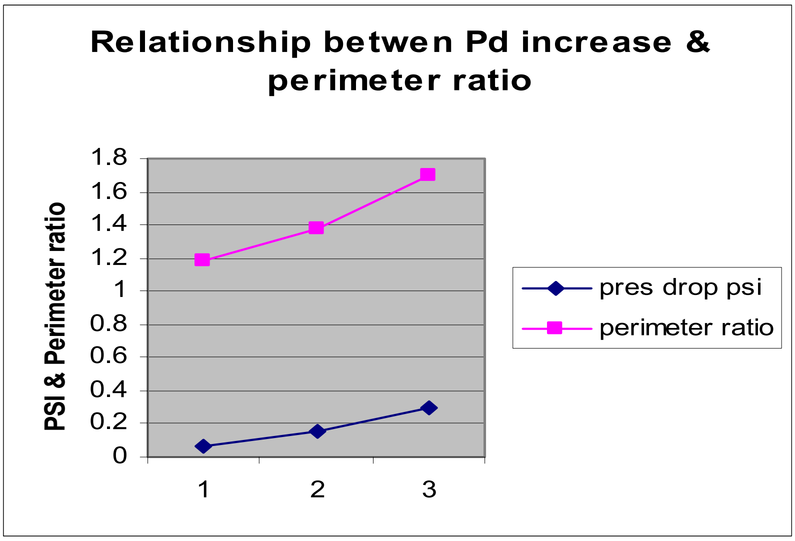


Fig 2

Benefits

The actual benefits achievable depend on a number of variables, which will differ from plant to plant and include feed type, feed cost, utilities costs, margin, and furnace availability. The benefit calculation should be carried out on specific data and can only be accurately calculated by each plant. However a general case can be constructed to illustrate the potential benefits obtainable using PEP tube. Based on a 10% increase in throughput (2.4 te/hr) with a furnace annual availability of 338 days and 85% furnace constrained (i.e. the additional production can only be used 85% of the time), the benefit depending on ethylene price would be around $1.3m/Annum. This figure is based on a contribution of $80/te and does not include any benefit from increased run length. The additional purchase cost of the PEP tubes, assumed to be 40% - 90% of plain bore coil cost, would be recovered in the first 4 months of operation.

(b) Maintaining feed rate & dropping TMTs

If there is no requirement to process additional feed the enhanced heat transfer characteristics of PEP tube can be utilised to allow the furnace to be operated with a reduced coil start of run tube metal temperature (SOR TMT). The furnace can be operated keeping all process reaction variables unchanged with the same flow rate, conversion, selectivity and yield. If this philosophy is employed the SOR tube metal temperature can be reduced by around 25ºC with no decrease in product produced. 35/45 microalloy (H46M) has a theoretical creep rupture life of 100,000 hrs operated continually at 1090ºC. A reduction of 25ºC would theoretically double the tube life. In practice however, it is not possible to achieve the theoretical service life of ethylene tubes whether cast or wrought, in any alloy, because a number of factors combine to damage the tubes, as described below. The PEP tube coil will experience a reduced SOR temperature but the end of run (EOR) temperature will converge on the final, run limiting, temperature. Damaging effects of carburisation, creep and thermal fatigue, as with all coils, also reduces the service life. However the reduction in temperature gradient over the run length has a marked effect on tube life and an increase of around 75% could be expected, this being dependent on the severity of operation. Increased coil life can be of importance if one of the plant objectives is to maximise coil life and minimise replacement expenditure.

Plant trials have shown that operating in this mode does not produce the level of coke found with an equivalent round tube. Commercial plant trials have been undertaken where finned tubes were installed in a furnace side by side with round tubes. The results from the trials exhibited a marked reduction in pressure drop over the duration of the run (fig 3). The test also confirmed that tube metal temperatures, as predicted, remained on average 26ºC lower with the finned tubes (fig 4). As operating conditions were identical for both finned and round tubes the only explanation for the significant improvement in run length performance with the finned tubes was that coke formation was suppressed, producing significantly less coke than in the round tubes[1]. The major operational benefits can be translated into both a significant increase in run length and a reduction in de-coke duration. In other trials run lengths have been increased by 125% (fig 5) and decoke times have been reduced by 50 %. Both of these benefits have a major impact on furnace economics.

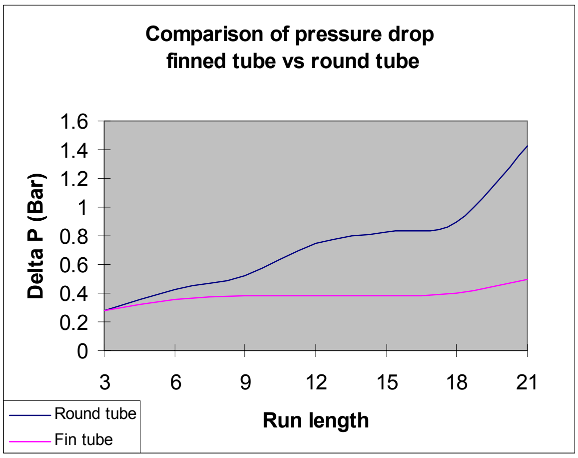


Fig 3

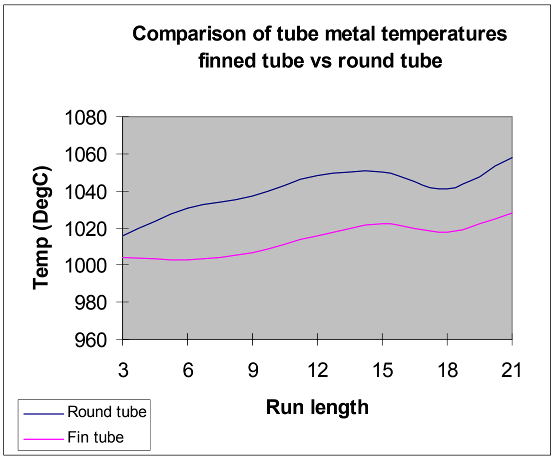


Fig 4

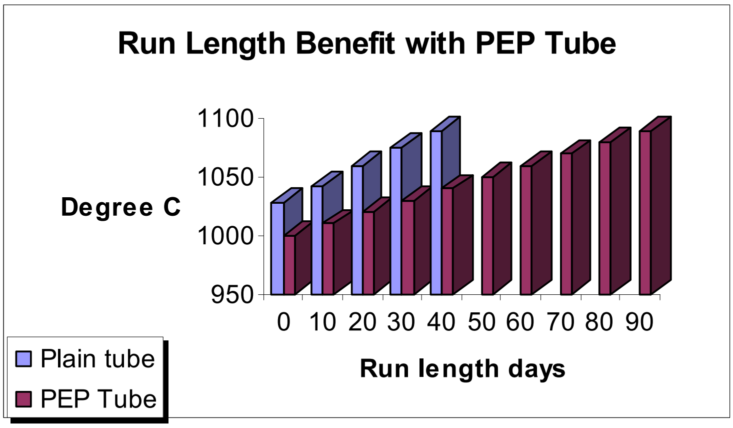


Fig 5

Benefits

As with the benefits calculated for increasing feed rates the actual benefits obtainable from operating with lower TMTs depend on a number of variables which will differ from plant to plant and include feed type, feed cost, utilities costs, margin, and furnace re-tube philosophy. The benefit calculation as with case (a) needs to be carried out on specific data and can only be accurately calculated by each plant. A general case can be constructed to illustrate the potential benefits obtainable using PEP tube. Assuming a severity of operation which gives a run length of 40 days followed by a 2 day decoke and the requirement to carry out a re-tube every 4 years with plain bored tube, PEP tube could potentially increase run length to 90 days, reduce decoke time to 1 day and increase coil life to 7 years. Assuming a contribution of $80/te, the accumulated benefits of additional production obtainable from increased furnace availability and coil life would be $512K/a. Based on an increased coil cost of between 40% and 90% the maximum pay back time would be at most 10 months.

(c) Maintaining TMTs and feed rates similar to plain tube

This mode of operation allows a greater heat input into a feed flow rate unchanged from plain tube operation. This operating mode has the effect of increasing conversion of the feed to other products. To be able to take advantage of this increased conversion selectivity has to be at least maintained. Selectivity is a function of residence time and hydrocarbon partial pressure so tube parameters have to be chosen to ensure that process conditions match those of the plain tube. If this is done neither the residence time nor partial pressure are altered. Maintaining an unchanged tube metal temperature profile from start to end of run would increase the heat energy supply to the feed. Provided that the feed being processed does not overcrack with the increase in heat energy (e.g. ethane), production benefits can be realised from greater conversion. Care should be taken with this strategy, as any tendency to over crack would produce coke, shortening run length.

Summary of benefits using PEP Tube

	Case (a) – Additional Feed	Case (b) – Lower TMTs
Additional run length from reduced de-coke (days)	0	11
Additional feed processed (te/a)	(10%) 16,548	5924
Additional feed benefit $/a)	1.3m	430k
Coil life extension (Years)	0	(75%) 3
Benefit from longer coil life – 1 less shutdown $/a)	0	82k
Total benefit $/a)	1.3m	512k

Cases (a), (b) and (c) set out distinct operating philosophies but in practise a combination of feed rate increase, temperature (TMT) decrease or any given process parameter can be designed for, to supply a given product slate to suit individual requirements. On some sites the production requirements include a set propylene yield in addition to ethylene and this necessitates a different set of process reaction variables e.g. residence time and selectivity. These furnace design parameters are best carried out by a furnace vendor with specialised knowledge but PEP Tube can be produced to the dimension and profile necessary to give the conditions required.

Flexibility

The cases described above are for coils converted wholly to PEP tube. There exists the possibility that a furnace designer may wish to incorporate PEP tube into a specific section of furnace coil to achieve a certain set of cracking conditions. This is wholly acceptable as part of a properly engineered design and provides the designer with the capability to incorporate space and efficiency enhancing features that would not be available with centrifugally cast plain bore or wrought finned tube. It is not possible to set out the financial benefits from incorporating PEP tube in this way as each design would be unique.

New furnace considerations

The cast tube employed in a cracking furnace is arguably the single most expensive item in the furnace and as such each furnace designer concentrates on the optimisation of the coil design. The dimensional parameters of the coil are designed to control the process dynamics to give the maximum conversion and yield of required products from a given feed slate.

The designer's drive is to produce a radiant box as small as possible, minimising capital expenditure but with the capability of inputting sufficient heat energy to give the required severity, via floor or wall burners, to initiate the chemical cracking reactions but with a pressure and residence time consummate with the required selectivity.

Paralloy Ethylene Profiled Tube gives a unique opportunity because of its high surface area to volume ratio to design a physically smaller radiant firebox, provided the required burner configuration can be achieved, than would be possible using plain tube. If furnace footprint is not a problem then the production per furnace can be maximised using PEP Tube.

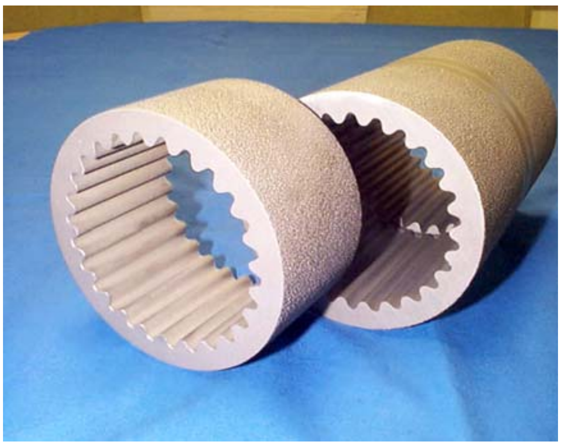
PEP Tube allows the furnace designer a degree of design flexibility unrivalled in the history of radiant firebox design. A decision to include PEP Tube at the initial design stage allows the other components of the furnace, convection bank, burners, heat flux; control valve sizing etc. to be designed such that any constraints on increased production can be addressed.

By increasing the overall thermal efficiency of a furnace utilising the high heat transfer characteristics of PEP Tube the reduction in NOx produced per te of feed processed or te of product formed can be used as part of a NOx reduction programme.

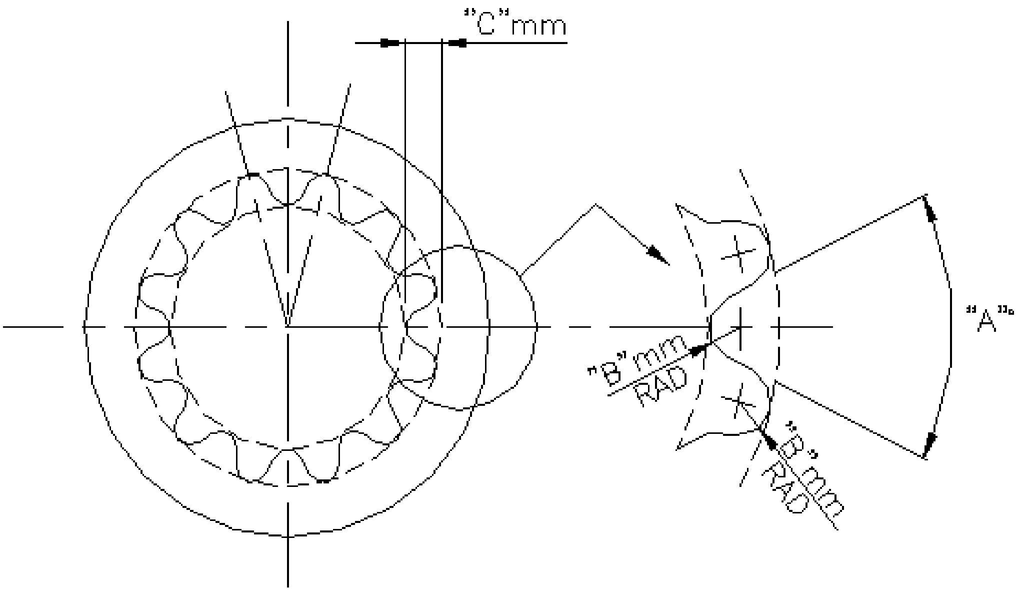
Depending on the fuel gas control scheme employed, a decrease in fuel gas use may be experienced but any fuel gas saving is small in comparison to other savings and has not been included in the overall PEP benefit calculation.

Tube profile

For most applications the profile is both symmetrical, sinusoidal and typically the ratio of pitch to amplitude has a value of between 2 and 4. For all applications there is an optimum profile to give optimum process dynamics. This must be ascertained if the maximum benefits are to be realised. For small-bore tube this could be in the range of 8 or 10 nodes or with large bore tubes over 4" ID it can be 18 to 26 nodes. By ensuring a profile with no sharp valleys stress concentration can be eliminated ensuring



that no cracks initiate within the profile. The shallow bottomed sinusoidal waveform minimises the possibility of accelerated coke formation in the valleys.



12 FIN TUBE

The current 'Fin Type' can be described as an internal and an external radius joined together by a tangential line to form a taper tooth fin.

Fin Gradient – defined as the angle between the flanks of the fin

This could be regarded as the most important parameter for Fin Tube. The gradient will be determined by the combination of the number of fins to be produced, the inside diameter of the tube and by the size of the tip and root radii. The limitation of all these features can be expressed by the **included angle of the GAP (A)** between successive fins.

This value should not be below 30 deg.

Fin Tip and Fin Tip Radii (B)

The radii can be adjusted in some instances to improve the Fin Gradient. The radius at the Fin Tip and Root should not go below 2.0 mm.**Fin Height (C)**

The height of the Fin in general is not critical for the ECM process. However the greater the height of the Fin the more material has to be removed to fully form the internal shape of the tube. This has the effect of reducing the speed at which the fins can be formed and hence can be more costly to produce.

Surface finish

When comparing the surface finish of traditional plain tube, wrought finned tube, spiral weld beads and PEP Tube, the advantage of PEP Tube in comparison to the others can be found by examining the microstructures of the bore surface and consideration of the finishing process.

(a) The profile formation on the bore of PEP Tube is formed by non-contacting electrochemical removal of material from the internal surface of a plain tube. This process is carried out by slowly drawing a high precision precisely shaped electrode, in the presence of electrolyte through the bore of the tube. The result is a fine, uniform surface finish that is free of surface defects in comparison to tool machining, spiral weld deposition and wrought tube formation.

(b) The process of drawing a wrought tube through the shaped die can cause marks, striations and small tears especially along the peaks of the fins. These results of the extrusion process provide convenient sites for initial coke formation and can allow the ingress of carbon into the surface due to the problematic formation of protective oxide at these defects.


Wrought tube


PEP tube

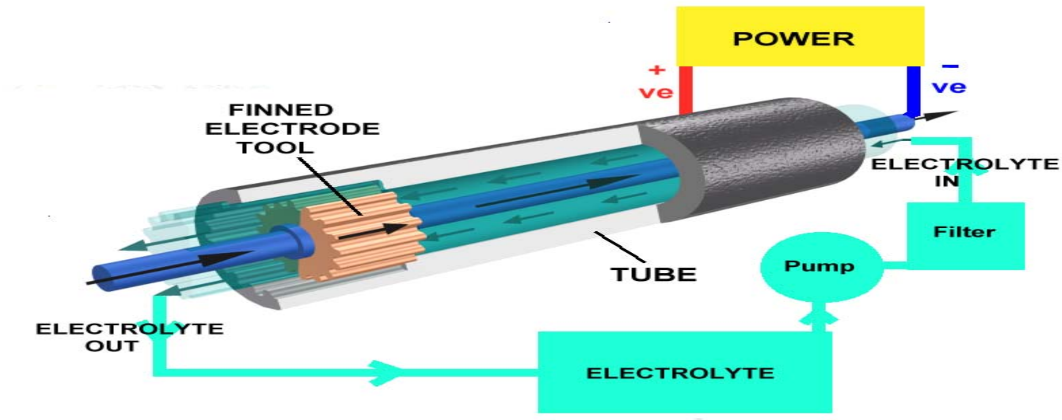
(c) When any machining operation is carried out using a tool with a finite tip dimension and a given feed rate, a tool track is left on the machined surface. These machining marks, fine as they may be, effectively increase the bore surface area exposing additional Ni and Fe catalyst sites required to initiate the formation of catalytic coke

The smooth, defect free, surface is arguably the reason why some operators have seen marked improvement in furnace run length. Run improvements of 125% have been realised in service with de-coke duration reduced by 50%.

Profiling operations

The start point of the profiling operation is the traditional centri-cast furnace tube. These represent the best materials available with the capability of operating up to 1150ºC.

The dimensionally accurate profile formed on the bore of the cast furnace tube is formed using electrochemical machining (ECM). ECM is not a new process but its use to form a profile in the bore of a cast tube is unique to Paralloy[2]. The basis of this operation is the controlled (anodic) dissolution of the tube wall using a cathodic tool with the same shape as that required on the bore. An electrical current is passed between the tube and tool via an electrolyte flowing in the small annular gap between them. By controlling the variable parameters a very accurate profile is transferred to the tube wall and because the process is non contacting the resultant surface finish is defect free.

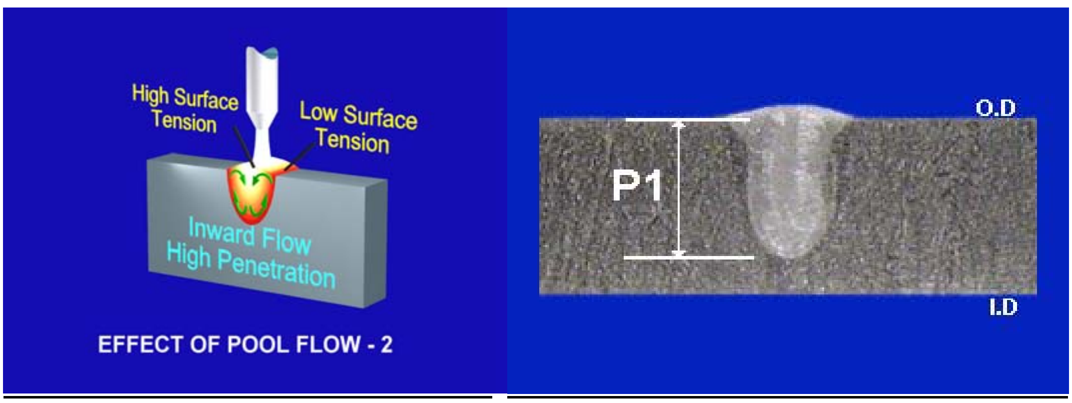


Paralloy have embarked on a major investment strategy that has allowed new ECM machinery to be commissioned at Billingham ensuring close control and cost optimisation of the forming process. Employing and training special technicians to undertake its operation have backed up the capital investment on machinery.

Induction bending

If swept bends are parts of the plain tube design this requirement can be incorporated in a PEP Tube coil. It is not possible to use ECM to impart a profile to a static cast component such as a return bend. The ECM operation has no effect on the cast properties of the tube and the familiar benefit in terms of strength, carburisation, creep resistance are not impaired.

Welding



The traditional method of welding finned tube sections together was to form a weld prep by machining a small turn back on the bore removing a small area of fining, typically 3mm on each tube. A traditional “J” prep on the outside diameter completed the profile. While this method of preparation has caused no problems Paralloy have developed a “Para-tig” welding process that allows the accurate matching of the fins in both sections of tube prior to welding without the need to machine back the fin profile. Using this method the profile can be maintained along the length of the tube.

Using a special flux developed by Paralloy, a mixture of inorganic powders suspended in a volatile liquid medium and incorporating an electronically controlled pulsed welding current the surface tension of the weld pool is altered providing a narrow weld profile with a minimum of filler wire. When using the traditional welding method the minimum tube wall thickness and the strength of the tube is dictated by the dimensions of the machined weld prep with fins removed. With the possibility of welding with no internal machining it should be possible to design tube wall thickness to give a lighter tube. Any weld bead intrusion into the bore of a round tube causing turbulence must cause a major pressure drop in the tube. In contrast to the technology that deliberately applies an internal restriction to flow, Paralloy ensures that no pressure drop intrusions are present following welding.

Available materials

All of the traditional alloys are capable of being profiled using electrochemical machining HK, HP Nb Mod, HP Microalloy and 35/45 micro alloy. Any operator changing to PEP Tube can therefore continue to use the alloys with which they are familiar, maintaining the material benefits already being experienced.

Other furnace considerations

The following list comprises a selection of furnace parameters that should be addressed as part of any engineering study. The list is not comprehensive and does not indicate that the use of PEP tube would cause a problem with any of them. It would be prudent to include these checks as part of any study to ensure that the full capability of the finned tubes can be achieved. The list may look daunting but not all items may require modification and the cost is normally small as a percentage of the overall cost, while the benefits are substantial.

Coil inlet venturi
Coil inlet venturi throat dimensions are calculated to ensure that the feed enters the furnace at sonic velocity thus ensuring an even flow to each coil in a furnace. Projected process conditions must be checked to ensure this remains the case. In some instances a small dimensional change to the throat diameter and / or inlet and outlet angles may be required.

Convection bank heat duty
Additional feed to be cracked must be pre heated in the convection section of the furnace to a temperature just below that required to crack the feed (typically around 650ºC) Additional feed will impose an additional load on the convection bank to allow full pre-heat. Other process streams from the convection section such as superheated steam may also be increased.

Coil support system
As a result of the profiling process and small tube dimensional changes there will be an increase in coil weight. The way that the additional loads resulting from the weight are distributed through the components of the support system will depend on coil configuration and the suspension system employed. The modification resulting from these changes can be as simple as adding additional counter weights or load springs

Burner heat release
Burner vendors normally design their burners to include an over-design margin resulting in unused heat capacity. If required this can be tapped to give required additional heat release.

Flow meters and control valves
Re-ranging of feed, dilution steam and fuel gas meters may be required.

Conclusions

1. A furnace fitted with PEP tube can handle around 10% additional feed than a plain tube furnace.
2. Maintaining feed rate can allow a reduction in TMTs of 25ºC that may lead to a coil life extension of 75% with PEP tube.
3. In general PEP tube has a much reduced coking rate and shorter decoke times than plain tube.
4. Unlike other profiles, results from Commercial Operation prove that PEP tube has a negligible effect on coil ΔP
5. For either case of Additional Feed Rate or Lower TMTs the additional investment for PEP tube will pay for itself in 4 to 10 months.

References

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