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Production Carburising in LPG/CO_2 Atmospheres for Energy and Cost Savings

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A joint Japanese/Indian development, the FC-35 carburising process is well-established in the production environment, with some 70 installations (predominantly sealed-quench furnaces) now operating in India. Compared with traditional endothermic-gas-type treatment, it is claimed to promote shorter process times, enhanced "throwing ability", reduced furnace conditioning requirements, lower atmosphere costs, savings in floor-space requirements, and high levels of post-treatment cleanliness.

INTRODUCTION

The drive for energy and cost savings in supplying a suitable base atmosphere for carburising and related processes has been with us for a considerable time.

A breakthrough was achieved, in the early 80's, with the development and application of nitrogen/methanol atmospheres as an alternative to the classical endothermic atmosphere. This eliminated the need for the endothermic gas generator and its associated running costs[1,2]. The advent of on-site PSA air separation and similar equipment has maintained the cost of nitrogen at an acceptable level. However, the escalating cost of methanol, and the necessity to ensure its constant and pure quality, has meant that this method of supplying furnace atmosphere has lost some of its attractiveness.

The simplified approach to carburising atmospheres of the hydrocarbon/air direct-feed system has met with reasonable success, especially since control was enhanced by the development and use of multi-gas analysis techniques and effective oxygen probes[3].

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The FC-35 *(Fine Carburising®)* process, using hydrocarbon/carbon dioxide (CO_2) atmosphere, was originally introduced in Japan[4]. Further development in India, for application in a production situation, verified the energy and cost savings achievable whilst producing excellent metallurgical quality. In addition, the 'throwing' ability of the process has facilitated the carburising of components of difficult geometry.

The FC-35 process is synonymous with accelerated processing, shorter furnace conditioning time, reduced atmosphere costs, savings in floor space and excellent standards of post-heat-treatment cleanliness.

In India, where piped gas is not common, liquefied petroleum gas (LPG) is stored in and consumed from large "bullet" installations (5/10tonne bulk-storage vessels) in most parts of the country. In addition, the strict environmental and explosives directives require extensive space for a LPG bullet installation. Hence, the use of endothermic gas generation from LPG feedstock is not preferred. The availability, price and toxic nature of methanol is also discouraging users from following the nitrogen / methanol route.

The FC-35 ACM process requires very small amounts of LPG, which, in India, are obtained from industrial 19kg cylinders, normally connected to a cylinder bank. CO_2 is also readily available in typical 50kg cylinders. The installation cost of the LPG/CO_2 cylinder banks is very low as compared with a large LPG bullet installation or a PSA nitrogen generator / storage vessel with methanol dosing system.

Recognising the advantages in terms of cost and time saving, India's Hightemp Furnaces Ltd. developed the FC-35 process, with LPG initially, in their commercial heat treat facility using a sealed-quench furnace.

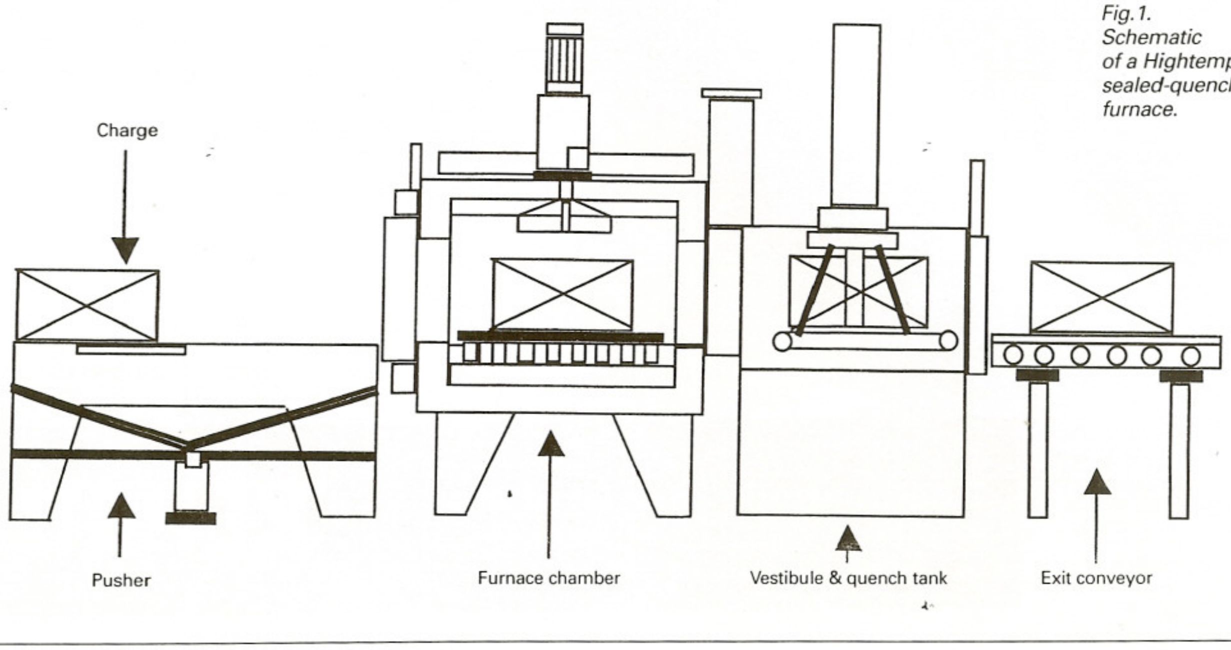


Fig. 1. Schematic of a Hightemp sealed-quench furnace.

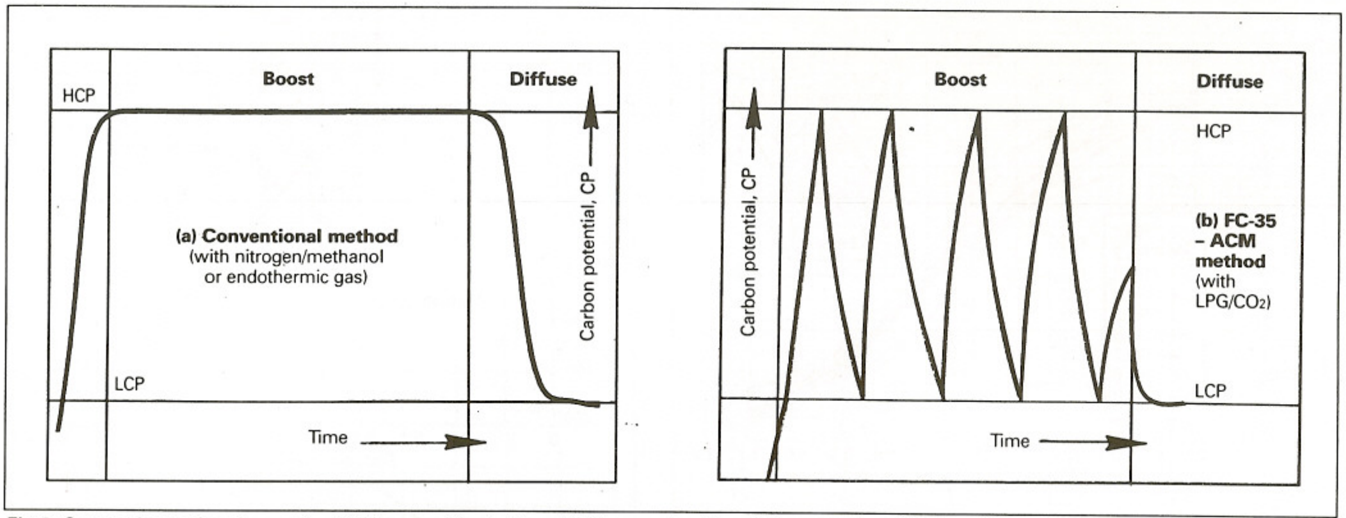


Fig.2. Comparison of carbon potential/time profiles in boost/diffuse carburising: (a) conventional processing with endothermic gas or nitrogen/methanol; (b) the FC-35 "amplitude" carburising method with LPG/CO_2.

THE FC-35 (ACM) PROCESS

The FC-35 ACM process as described is applicable to the sealed-quench furnace *(Fig. 1)*.

Carburising atmosphere is produced in-situ from a mixture of LPG (composed of approximately 60% butane and 40% propane, as available in India) and commercial-quality CO_2. The process was originally developed in Japan using propane as the hydrocarbon gas.

A standard 1m^3 effective-volume Hightemp sealed-quench furnace requires a total flow rate of some 4l/m (0.24m^3/h) of the LPG and CO_2 mixture, as compared with about 10-12m^3/h of endothermic gas or nitrogen/methanol cracked gas in the same furnace.

The FC-35 ACM process uses a pulsing technique between high and low carbon potential, regulated by an automatic oxygen-probe control system, during the boost stage of the normal boost/diffuse cycle. This technique is referred to as the Amplitude Carburising Method (ACM).

Normally, approximately 75% LPG and 25% CO_2 makes up the 0.24m^3/h base gas mixture utilised. It has been established that an effective FC-35 production process is possible with propane alone, or indeed methane, replacing the mixed LPG hydrocarbons.

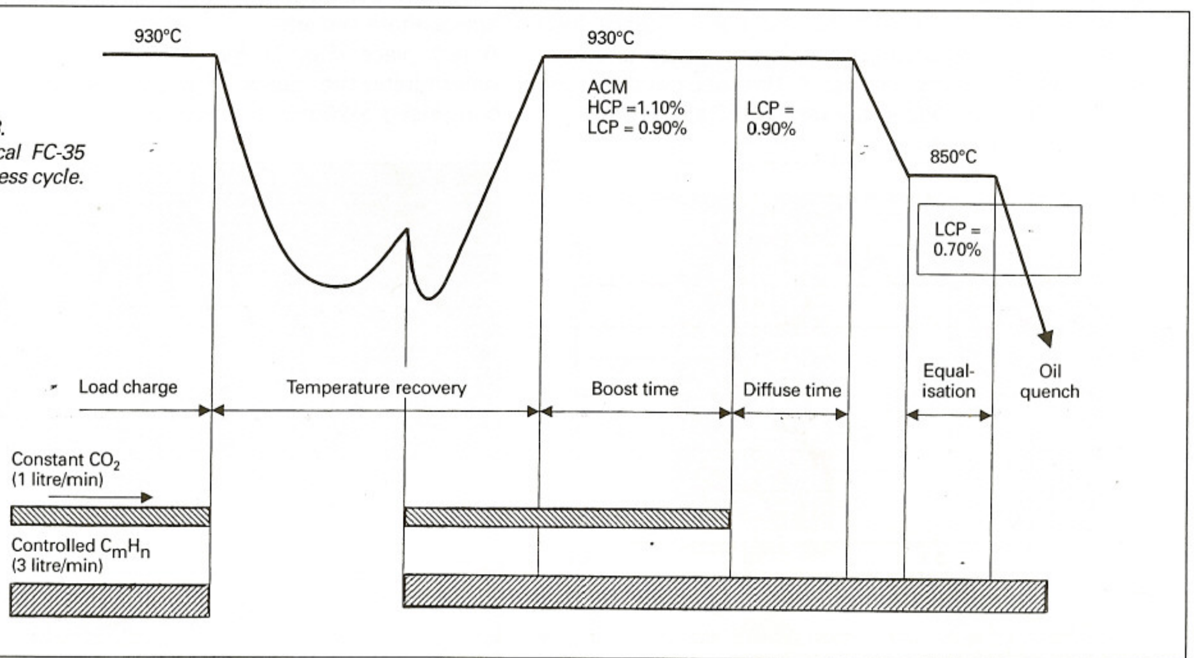
Process cycles follow the classical boost/diffuse technique. *Fig. 2* compares carbon potential/time profiles in boost/diffuse carburising with conventional nitrogen/methanol or endothermic atmospheres and the FC-35 ACM method with LPG/CO_2.

In the conventional method, the boost stage is at a high carbon potential (HCP), of the order of 1.0%, and diffusion at a lower carbon potential (LCP), such as 0.9%. In comparison, in the FC-35-ACM method, the carbon potential is pulsed between HCP and LCP, where HCP can be comparatively higher (example: 1.1%) and LCP is controlled at 0.9%. This confers an advantage of processing at higher carbon potential to achieve reduced process times.

A typical process cycle would be as follows *(Fig. 3)*:

- Prewash.
- Condition furnace atmosphere for carburising at 930°C (carbon potential 0.8%).
- Load furnace and recover to 930°C – carbon potential controlled automatically during recovery in relation to temperature.
- Boost pulse carburise at 930°C for required period (amplitude carburising method) – e.g.: HCP 1.1%; LCP 0.9%. Maximum LPG gas volume flow is set and the carbon potential is pulsed between a high set point (HCP) and low set point (LCP). The carbon potential is controlled by varying the LPG flow automatically by means of a motorised valve. The CO_2 volume is set at a constant value.

Fig.3. Typical FC-35 process cycle.



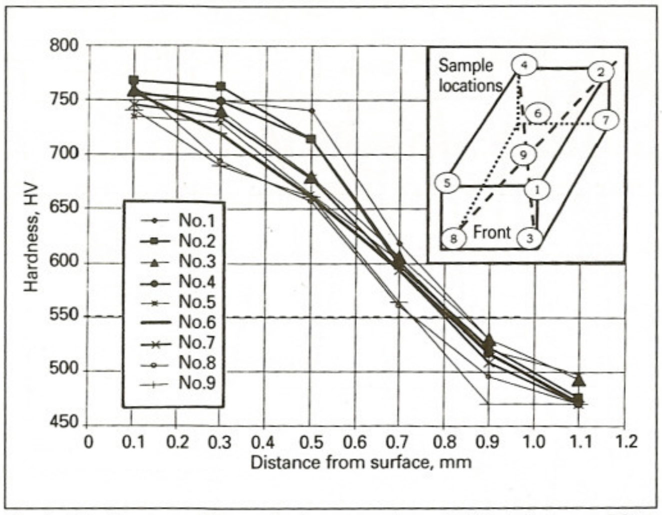


Fig.4. Hardness profiles of nine samples distributed in a FC-35 carburising load as shown.

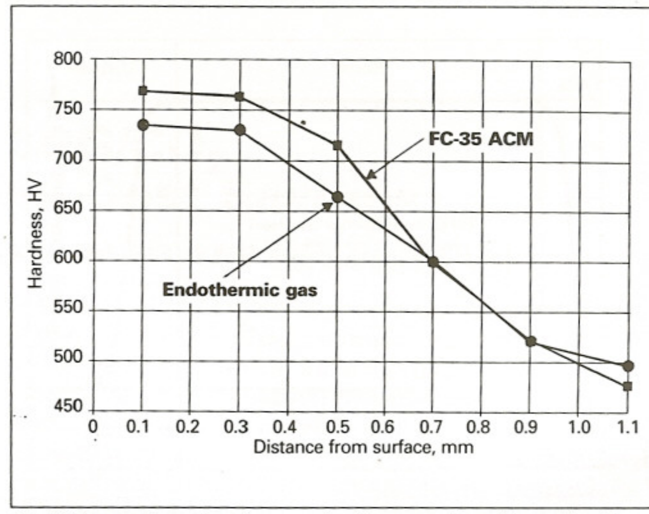


Fig.5. Comparison of rocker-arm hardness profiles after carburising in FC-35 ACM atmosphere and in endothermic gas.

- Diffuse at 930°C for required period at LCP.
- Drop to hardening temperature. Carbon potential can be set to required value. Equalise temperature and oil quench.
- Wash and temper.

PROCESS EVALUATION

Evaluation of the FC-35-ACM process was carried out using a series of nine test pieces in a batch (placed at eight corner positions and the centre of the charge basket) in order to assess the uniformity of the treatment results. Test pieces were examined for case quality, surface hardness, carbon gradient, hardness profile and cleanliness.

These trials were conducted with a typical full load of automobile rocker arms (material : 20MnCr5 – DIN 17210-69) of the following composition:

Carbon	0.17 – 0.22%
Silicon	0.15 – 0.40%
Manganese	1.10 – 1.40%
Phosphorus	< 0.035%
Sulphur	< 0.035%
Chromium	1.00 – 1.30%.

Surface Hardness

The variation in the surface hardness on the nine sample test pieces was from 775 to 810HV.

Hardness Profiles

The hardness traverse results on the same furnace load revealed a close relationship between test pieces, within acceptable limits as shown in *Fig. 4.* The case depth in nine samples, to 550HV, varied in the range 0.75 to 0.85mm.

A comparative test was also carried out on nine sample test pieces in an endogas atmosphere. Component hardness profiles are compared with those imparted in the FC-35 process in *Fig. 5.*

Carbon Gradient

A comparison of carbon gradients (measured on an emission spectrographic analyser) was carried out on rocker arms treated in the FC-35 ACM and endogas processes. The results, shown in *Fig. 6,* were considered to be of an acceptable quality standard.

Cleanliness

The general level of cleanliness of components processed by the FC-35 process is excellent and they are totally free of soot. Obviously, however, this requires a disciplined approach to furnace maintenance and operator skill as for any carburising process. A periodic burn-out of the furnace using the FC-35 process was considered necessary to maintain a high level of freedom from soot on the surface of the components.

The photograph in *Fig. 7* shows typically densely-loaded components processed in FC-35 atmosphere.

THROWING ABILITY

Following the excellent results obtained from processing of standard components, further tests were conducted in order to evaluate the 'throwing ability' of the FC-35 atmosphere system.

A test piece *(Fig. 8)* was designed with the purpose of determining the quality of processing in blind holes. This comprised a 20mm-diameter bar of 60mm length with a

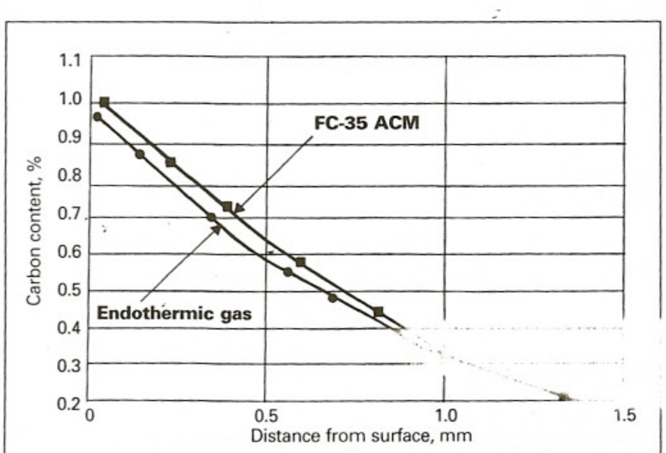


Fig.6. Comparison of rocker-arm carbon profiles after carburising in FC-35 ACM atmosphere and in endothermic gas.

Fig.7. A typical charge after FC-35 carburising.

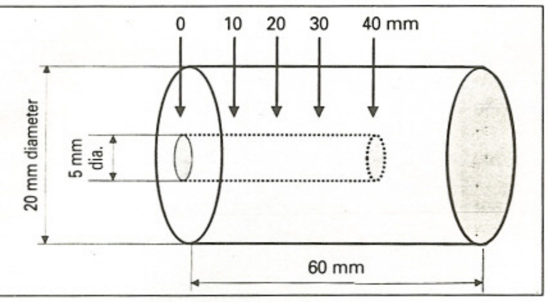


Fig.8. Blind-hole test piece.

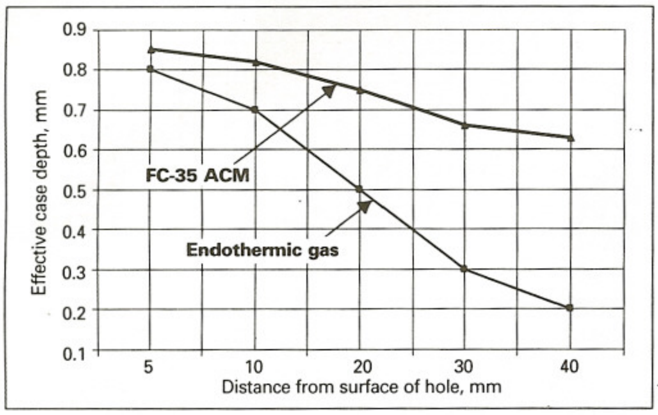


Fig.9. Effective case depths down the blind-hole after FC-35 and endothermic-gas carburising.

Table 1. Injector valve test data.

Sample location	Surface hardness, HRC	Core hardness, HV	Effective case depth, mm		
			Outside diameter	Inside diameter	Tip
1	58.7	369	0.74	0.59	0.58
2	59.7	386	0.71	0.57	0.56
3	59.8	375	0.65	0.56	0.59
4	60.1	361	0.67	0.56	0.59
5	58.6	383	0.73	0.59	0.68
6	58.4	373	0.71	0.64	0.59
7	58.4	399	0.70	0.59	0.53
8	58.9	406	0.69	0.60	0.60
9	58.8	340	0.61	0.51	0.55
10	58.7	350	0.62	0.54	0.58
11	59.4	374	0.68	0.58	0.62
12	59.3	363	0.68	0.54	0.70
13	60.1	420	0.77	0.61	0.64
14	59.2	398	0.67	0.56	0.60
15	61.2	401	0.76	0.63	0.66
Average	59.29	379.9	0.693	0.578	0.605

5mm-diameter hole drilled from the end face to a depth of 40mm. The specimens were carburised in a sealed-quench furnace using FC-35 atmosphere. The total boost/diffuse time was 4.5 hours at a temperature of 930°C, followed by equalisation at 830°C for 30 minutes and quenching in cold oil. Tempering was carried out at 130°C.

The results were compared against those of the same test carried out with endothermic atmosphere. *Fig. 9* demonstrates that the 'throwing ability' of the FC 35 process was far superior to that offered by endothermic gas.

A further test was carried out processing diesel fuel injectors, which are universally recognised as being particularly difficult to treat to an acceptable standard. Some fifteen test pieces were distributed throughout the load for this evaluation. The total boost/diffuse time was 3 hours at a temperature of 900°C, followed by equalisation at 830°C for 45 minutes and oil quenching. Tempering was carried out at 170°C.

It can be seen clearly from the results (*Table 1*) that the 'throwing ability' of the FC-35 process is dramatically improved, compared with that of endothermic atmosphere.

COST SAVINGS

In view of the low flow rates of LPG and CO_2 used in the FC-35 method, compared with classical atmosphere systems, the associated savings are obvious. It has also been established that the FC-35 process enables a reduction in cycle time of some 20-30% in deep case depth applications.

Components were processed to a 1.40 to 1.65mm case depth requirement with a 25% time saving in the FC-35 process. Components met a 0.90 to 1.10mm case depth requirement with a reduction of 22% in treatment time. These results are both based on processing in a sealed-quench furnace and time reductions were calculated with reference to nitrogen/methanol atmospheres.

Cost comparisons have been carried out both in Japan and in India and have also been projected for a typical UK operation using a sealed-quench furnace.

In Japan, atmosphere costs for the FC-35 process are quoted as 15% of the atmosphere costs for endothermic atmosphere processing. A similar evaluation carried out in India demonstrated that the FC-35 atmosphere costs were

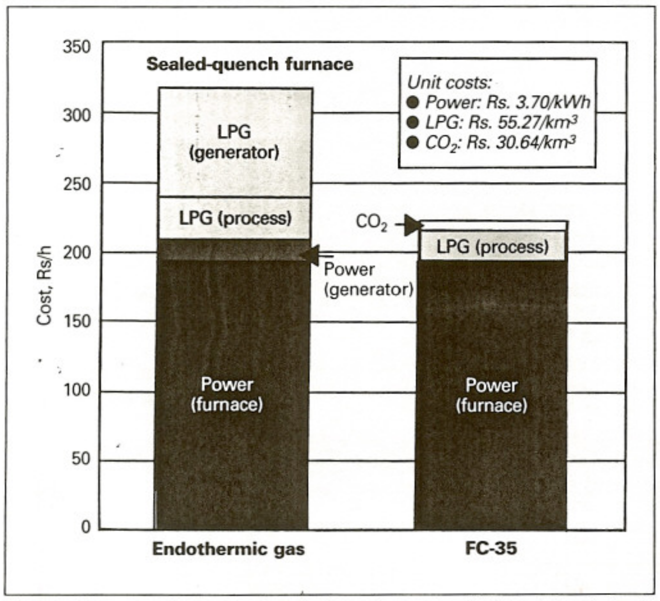


Fig. 10. Comparative costs of endothermic-gas and FC-35 carburising in India. At Jan. 2002, £1 = 70 Rupees (Rs).

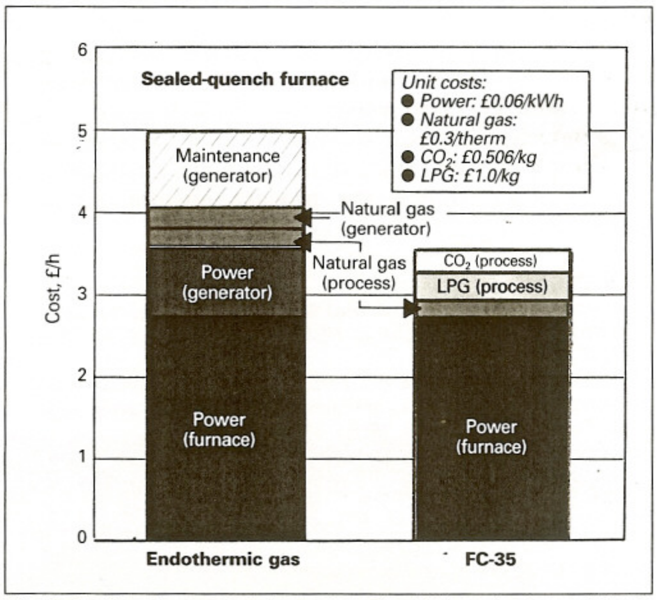


Fig. 11. Projected comparative costs of endothermic-gas and FC-35 carburising in the UK (based on the utility costs listed in Table 2).

Table 2. Basis for UK costs depicted in Fig.11.

Cost item	Endothermic-gas process		FC-35 process	
	Cost detail	Total cost/hour (£)	Cost detail	Total cost/hour (£)
Furnace heating	80kW x 40% x £0.06/kWh	1.920	80kW x 40% x £0.06/kWh	1.920
Motor	25kW x 30% x £0.06/kWh	0.450	25kW x 30% x £0.06/kWh	0.450
Power control	6kW x 100% x £0.06/kWh	0.360	6kW x 100% x £0.06/kWh	0.360
Heating endo generator	35kW x 40% x £0.06/kWh	0.840		
Feedstock endo generator	*75ft^3/h x £0.3 per therm	0.225		
Addition gas	*25ft^3/h x £0.3 per therm	0.075		
LPG process			0.3kg/h x £1.0/kg	0.300
LPG short purge			0.05kg/h x £1.0/kg	0.050
Gas curtain burner	*20ft^3/h x £0.3 per therm	0.060	*20ft^3/h x £0.3 per therm	0.060
Gas pilot burner	*50ft^3/h x £0.3 per therm	0.150	*50ft^3/h x £0.3 per therm	0.150
Gas ring burner			*1ft^3/h x £0.3 per therm	0.003
CO_2 process			0.55kg/h x £0.506/kg	0.278
TOTAL COST/HOUR		**4.080**		**3.571**
Maintenance	Est. £0.25 per hour	0.250		
Spares and catalyst	Est. £0.18 per hour	0.180		
Regeneration	Est. £0.03 per hour	0.030		
Depreciation	Est. £0.44 per hour	0.440		
Process reduction time			Carburising time (Ct) factor = (0.80 x Ct)	–0.714
Realistic cost/hour		**4.980**		**2.857**
Cost per charge for 6 hours cycle time		**29.88**		**17.14**

**1 therm = 100 ft^3/h; 1m^3 = 35 ft^3/h.*

28% of those for treatment in endothermic atmosphere. *Figs.10 and 11* show the comparative costs in India and the projected costs for the different processes in the UK. The projection of costs for the UK operation is based on utility costs listed in *Table 2.*

CONCLUSIONS

It is apparent from the evaluation work carried out that the following observations can be made:

1. The FC-35 method is an effective and viable carburising process, which results in a quality product.
2. The FC-35 process has the ability to carburise components of difficult geometry.
3. Costs associated with the provision of furnace atmosphere are such that extensive savings are available in comparison with the costs of traditional gas carburising processes.
4. Savings are available from a reduction in process cycle times.
5. Further cost and energy savings are available by eliminating the requirement for endothermic generators. This also results in saving floor space.
6. The reduction in gases exhausted into the atmosphere (waste exhaust gas is 2% of that from the endothermic gas method) makes the process environmentally acceptable.

REFERENCES

1. **Bowes R. G., Sheehy B. J. and Stratton P. F.** A new approach to nitrogen-based carburising. *HEAT TREATMENT OF METALS. 1979.3, Vol.6,53-58.*
2. **Bennett K. and Withers E.** Operating experience with nitrogen/methanol atmospheres in continuous carburising furnaces. *HEAT TREATMENT OF METALS. 1985.1, Vol.12,17-19.*
3. **Hewitt W.** A user's view of carburising with direct-feed hydrocarbon/air atmospheres (*Supercarb*). *HEAT TREATMENT OF METALS. 2000.2,Vol. 27,33-37.*
4. **Naito T. and Ogihara K.** Examined the direct carburizing method. *1995 Carburizing and Nitriding with Atmospheres (Proceedings of the Second International Conference on Carburizing and Nitriding with Atmospheres, Cleveland, 6–8 Dec. 1995) ASM International, 1995, 43-51.*

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