



THE THEORY AND ECONOMICS OF ATMOSPHERE SELECTION

Metal components have been routinely heated using both gas generators and industrial gas atmospheres for many years. This article imparts an overview of various atmosphere systems' features and benefits.

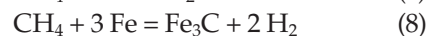
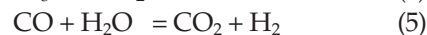
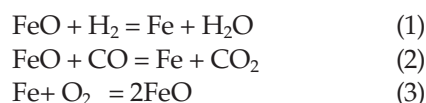
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The metals processing industry is faced with heightened competitive pressure brought on by the global economy. As industry globalization accelerates, new technology has become the driving force in processing and manufacturing industries. Much of this technology comes from the industry's suppliers. Typically, as technologies are advanced, productivity improvements are needed to compensate for the additional costs of new product features. This is true of controlled atmosphere systems.

Theoretical Considerations

The chemical and physical properties of a part surface resulting from a thermo-chemical treatment depend mainly on the composition of an active gas atmosphere. In general, atmospheres contain chemical compounds that at certain temperatures decompose and are transferred to the material surface. For instance, the major reactions taking place at a steel part surface during heat treatment in a carbon-controlled atmosphere are:



The equilibrium constant of a water/gas reaction (5) at any temperature is numerically equal to the ratio of the equilibrium constants for the reactions (1), (2), which involve the reduction of iron oxide. Therefore, the reaction tendency of controlled atmospheres containing CO, CO₂, H₂O, and H₂ is indicated by pCO/pCO₂ or pH₂/pH₂O ratios. Interestingly, the equilibrium of the reactions is not independent. If equilibrium is established for two of them it must necessarily be attained for the third. It should be noted that the higher the temperature, the smaller the required concentration of CO₂ relative to CO is to make an atmosphere oxidizing. Similarly, carbon deposition or decarburizing can be controlled by comparing the pCO/pCO₂ ratio, with that at equilibrium in the appropriate reactions. The water gas reaction is also significant in bright surface treatments, since this reaction is catalyzed by an iron surface, it may cause undesired roughening.

It can be assumed that an atmospheric composition remains constant in time if both pressure and temperature are stable and no species from the atmosphere are transferred to the steel surface in a clean environment. In reality, vacuum systems are the only commercially available systems that can, to some extent, shield from gas chemistry variations. The principles outlined above are equally applicable to the treatment of nonferrous and other metals.

Metal Treatment Atmospheres

For this article's purposes, atmospheres are defined as any gaseous atmosphere, other than air, used to protect steel or other material during heat treatment, which atmosphere can be varied and controlled within certain limits.

For simplicity, atmospheres are generally divided into *protective* and *reactive* compositions. Because of continuous improvement in tech-

Figure 1 — Atmosphere Classification

	REACTIVE	PROTECTIVE	
		NEUTRAL	INERT
Application	Case Hardening Decarb-Annealing	Annealing, Hardening, Tempering, Brazing, Sintering	Vacuum operations HIP
Components	Active: CO, CO ₂ , H ₂ O, C _x H _y , H ₂ , NH ₃ , etc. Base: N ₂ , Ar	Active: CO, CO ₂ , H ₂ O, C _x H _y , H ₂ , NH ₃ , N ₂ , etc. Base: N ₂ , Ar, H ₂	Ar/He, N ₂ /He, N ₂ /Ar/He
Surface changes	YES: • Composition • Time • Temperature	YES: • Composition • Time • Temperature	NO
Other surface structural changes	Not usual if controlled	Not usual	Possible
Furnace type	Batch Vacuum Continuous	Vacuum HIP Chamber Autoclave	Batch Vacuum Continuous Autoclave

nology and controls, further classifications of atmospheres have been developed to encompass their composition and application variations (Fig. 1).

Protective atmospheres prevent a metal's surface from discoloration, oxidation or carbon loss at elevated temperatures. The simplest protective atmosphere for metal treatment is inert gas (inert atmosphere). However, in industrial operations inert gas atmospheres offer no protection against the trace impurities (such as oxygen, moisture, and carbon dioxide), which are almost invariably present. Although inert atmospheres, as their name suggests, do not oxidize or decarburize, it is possible to have a neutral atmosphere, which contains reactive gases (such as CO, H₂, H₂O, CO₂) and will maintain a chemical equilibrium with the parts being processed. With a neutral atmosphere, there is no resultant chemical change in the part during heat treatment. Reactive atmospheres always contain reactive gases (CO, CO₂, H₂O, NH₃, and hydrocarbons) that change the chemical composition of the metal by adding or removing elements. The contents of a reactive gas atmosphere are dictated and

controlled to obtain the surface specification dictated by the part's end-use.

Atmosphere Systems

Atmosphere systems are defined here as an aggregate of equipment, technologies, and services that supply atmosphere gases used by the metals processing industry, and specifically in thermo-chemical treatment operations.

Metal components have been routinely heat treated, sintered, and brazed by part manufacturers using both generator (endo, exo, DA) and industrial gas atmosphere systems for nearly a century.

During the last 40 years, increased demand for better part quality and constant development of new processes have triggered a steady acceptance and use of industrial gas atmosphere systems. Industrial gases offer the advantage of cost effectiveness, flexibility, and reliability of supply. The development of on-site generation technology made industrial gas even more attractive to the heat treater.

Historically, the atmosphere generator and industrial gas atmosphere were viewed as competitive, rather than complementary, systems.

Pressed by the industry's quest for cost reduction, atmosphere generator, industrial gas, and other suppliers attempted to develop and deliver new atmosphere systems. Despite the vast amount of time and money spent on development of these systems, little effort was made to address their impact on productivity by either the user or the supplier.

Atmosphere supply systems, typically standard equipment, are well known in the industry. Nevertheless, variations in the part quality are normal day-to-day problems. Recent advancements in measurement methods changed atmosphere control practices from the independent measurement of single components (dew points, CH₄, CO, CO₂ or O₂) to continuous and accurate monitoring. Careful control is not simply a matter of elaborate equipment, it requires above all an accurate knowledge of which variables must be controlled, of which gas compositions tend to react with the metal, and how close the control must be in a given application. Today's precise atmosphere control methods have been adopted by progressive metal treatment facilities resulting in increased reliability of processes like case hardening, without regardless of which atmosphere gas is used. Additionally, the development of furnace and atmosphere control technologies lead to increased efficiency.

From the end-user's point of view, each metal processing operation needs a flexible supply system that can quickly adapt to provide the optimal furnace atmosphere, when parameters affecting product quality change.

Depending on the material being processed and the treatment required, plant technical personnel must select a furnace and an atmosphere pertinent to the application's part specifications. When selecting a suitable atmosphere for an operating facility one has to keep in mind future requirements like process variations and production changes. It is essential that the atmosphere mode of supply be dictated by a complete evaluation, from both technical and cost perspectives.

During the last 10 years, several papers have summarized the construction, operation, and cost/benefit comparisons of each commercially available system supplying controlled atmospheres.

Because atmosphere systems are

assumed to be mature technologies, their selection for a given operation is often made based on past experience or preferences. However, in order to evaluate the real impact on operational productivity it is suggested the following ques-

Table 1 — Economic Evaluation of Atmospheres (1)

Operational factors	Atmosphere Options			
	Units	Endothermic	Diluted Endo	N ₂ /H ₂
Number of furnaces	ea	9	9	9
Total furnace atmosphere flow	scf/h	20,500	20,500	20,500
Atmosphere composition (in furnace)				
N ₂	(%)	39.9	88.0	90.5
O ₂	(%)	—	—	—
CO ₂	(%)	0.1	0.1	—
CO	(%)	18.5	3.5	—
H ₂	(%)	39.9	8.0	9.5
H ₂ O	ppm	1.1	0.2	0.03
other (i.e.:hydrocarbon)	(%)	0.5	0.3	—
Purge/Safety gas	Scf/ mo x 10 ³	1,000	1,000	1,000
Dilution gas	scf/h	—	16,400	—
Operating hours/year	hrs/yr	8,000	8,000	8,000
Operating cycle	hr/day/wk	168	168	168
Capital equipment cost factors				
Atmosphere system capital cost	\$	450,000 ^E	150,000 ^E	—
Control and analytical equipment	\$	450,000 ^E	450,000 ^E	450,000 ^E
Installation at 20% of investment	\$	180,000 ^E	120,000 ^E	90,000 ^E
Other capital costs	\$	10,000 ^E	20,000 ^E	25,000 ^E
Total capital cost	\$	1,090,000^E	740,000^E	565,000^E
Time to amortize new equipment	yrs	10	10	5
Variable cost factors				
Industrial gas	%	6.9%	38.7%	64.9%
Natural Gas	%	21.4%	4.9%	0.0%
Cost of electricity	%	20.8%	20.4%	13.0%
Cost of water	%	0.8%	0.2%	0.0%
Adjustment and maintenance man-hour	%	6.3%	2.8%	1.2%
Parts as 8% of capital	%	9.1%	6.8%	4.2%
Annual Cost of capital (@5% interest)	%	34.7%	26.2%	16.7%
Quality savings factor	%	(2)	(2)	(2)
Environmental and safety savings factor	%	(2)	(2)	(2)
Other savings	%	(2)	(2)	(2)
Other variable cost factors	%	(2)	(2)	(2)
Furnace utilisation factor	%	100%	100%	100%
Economical evaluation summary				
Average monthly atmosphere gas volume	scf*10 ³ /mo	4,667	14,667	14,667
Capital Cost of supply system - compared to Nitrogen Hydrogen atmosperes	%	193%	131%	100%
Monthly Cost of supply systems - compared to Nitrogen Hydrogen atmosperes	%	94%	84%	100%
Cost of controlled atmosphere unit (3)	\$/100scf	0.45 ^E	0.40 ^E	0.48 ^E

(1) The data in this table is not exhaustive and is intended for illustration purposes only.

(2) Savings impact not illustrated

(3) Wider costs variation can occur depending on factors like: utilities price, atmosphere system and controls scope, quality and specs requirements, environmental regulation, interest rate, geography, etc.

E - Estimated value

Figure 2 — Process Atmosphere Suitability

GAS PROCESS	N ₂	N ₂ / NH ₃	N ₂ / C _x H _y	N ₂ / CH ₃ OH	N ₂ / H ₂	H ₂	Ar	Ar/ H ₂	He	Endo	Exo
Bright Anneal											
NonFe Anneal											
Decarb Anneal											
Alloy Steel Anneal											
SS Anneal											
Neutral Hard											
Carburizing											
Nitriding											
Tempering											
Brazing											
Sintering											
Galvanizing											
HIP											
Vacuum											
Cryo Treatment											

Color Coded Key: Light Blue = Industrial gas; Yellow = Atmosphere generator

tions be given careful consideration:

- What is the average labor cost per hour?
- How many shifts are there?
- How many hours per year does a direct labor person work?
- What is the total annual maintenance cost?
- What is the total annual operating cost?
- How many systems do you have in your plant?
- What is your time of payback for capital investment?
- What additional capital improvements are required?
- What is your current operating efficiency?
- What is the increase in efficiency required to justify investment?

For metals treatment facilities profitability is centered on product or process improvements that increase quality and yields while reducing scrap and defects. Economic evaluation of atmosphere systems includes the cost of production and use of these systems, and the savings generated by their use. Savings vary from user to user. Therefore, it is extremely difficult to present a general argument in favor of one atmosphere system over another.

Many companies have developed

their own methods of cost analysis. However, most of these models do not consider market changes and cost-of-ownership factors that affect the real productivity of the operation. Several of these factors are included in Table 1 for readers willing to perform more detailed evaluation and comparison of various atmosphere system options.

Conclusion

This paper has reported on atmosphere production systems, their cost, and their impact on a typical annealing, brazing, or carburizing operation. Unit operating cost for usual controlled atmosphere systems have been found to vary from \$ 0.25 to \$2.50 per 100 scf of atmosphere produced. These variations are mainly caused by the wide range of sizes and the variety of atmospheres required for a certain application.

It should be pointed out that ordinarily, the atmosphere cost per unit declines rapidly with increased capacity, while operating cost per unit of atmosphere produced is relatively constant. Readers may correlate the information of this paper with reported data on atmosphere performance and draw their own conclusions.

