

PRACTICAL ASPECTS OF PRODUCTION BRIGHT ANNEALING OF STAINLESS STEEL

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SYNOPSIS

Bright annealing is the annealing of stainless steel sheet and strip continuously in a controlled-atmosphere furnace (depicted). The furnace atmosphere system includes an ammonia storage tank, a dissociator, and an adsorption dryer. Furnace capacity depends upon its specific size, source, temperature, and cooling rate, as well as the emissivity of the material processed. Atmosphere problems are purity and nitrogen pickup. Purity of the dissociated ammonia gas depends upon initial raw ammonia contaminants and dissociator performance. Nitrogen pickup can be prevented by annealing in purified hydrogen atmospheres. Production problems include atmosphere system leakage, maintenance of a temperature head, strip cleaning problems, and crystallized surface. Fabrication problems have included soldering and drawing. The advantages of bright annealed strip are improved surface finish, reduced buffing costs, and improved corrosion resistance.

Bright annealing, as referred to in this paper, is the annealing of stainless steel sheet and strip continuously in a controlled-atmosphere furnace. This protective furnace atmosphere protects the steel from oxidation, thereby eliminating the usual pickling operations associated with conventional annealing. The surface finish, after bright annealing, is the same as it was in the "as cold rolled" condition. The furnace atmospheres are usually dry hydrogen or dry dissociated ammonia which is composed of 75 per cent hydrogen and 25 per cent nitrogen.

To produce the stainless steel required by the automotive industry, it was necessary to do considerable polishing and buffing to impart a satisfactory corrosion resistance, but competitive and economic conditions in the industry demanded corrosion resistance with minimum buffing. Various investigators found that conventionally annealed and bright pickled Type 430 stainless steel resulted in a chromium-depleted surface with reduced corrosion resistance. In addition, it was found that annealing in an inert atmosphere, such as dry dissociated ammonia or hydrogen, did not result in a chrome-depleted surface.

The joint efforts of the stainless producers and the builders of industrial

furnaces resulted in bright annealing furnaces that would provide a product which would be competitive with conventional annealed and pickled material in regard to operating costs, to meeting annealed properties, and so on, and yet would not change the surface, thus solving the corrosion (chrome-depletion) problem.

BRIGHT ANNEALING UNIT

The bright annealing unit is composed of the following major components (Fig. 1):

A Payoff reel or uncoiler.

D Shear—for preparation of the ends of the coils for welding.

K Welding unit—for welding of the coils for continuous operation.

F Strip or sheet cleaning unit—usually alkaline cleaner or trichlorethylene.

G Accumulators:

Entrance accumulator—main purpose to allow for time to weld the coils together.

Exit accumulator—main purpose to allow time for the removal of the coil from the take-up reel.

3 Annealing zone—containing inert atmosphere of dry dissociated ammonia or hydrogen. May be of muffle type or high purity refractory brick lined furnace type.

4 Cooling zone—containing inert atmosphere of dry dissociated ammonia or hydrogen.

J Take-up reel or recoiler.

In addition to the above, located at strategic positions are tension and speed control bridles, together with edge guides and steering rolls to ensure centering of the strip along the line.

ATMOSPHERE PRODUCING SYSTEM

The major components of the furnace atmosphere (dissociated ammonia) system are an ammonia storage tank, a dissociator for the cracking of ammonia to hydrogen and nitrogen, and an adsorbing dryer of the molecular sieve type with fully automatic controls for the further reduction of the dew point of the dissociated ammonia.

The ammonia dissociator consists essentially of one or more retorts filled with a catalyst, which is heated externally and through which gaseous ammonia is passed. The ammonia dissociates according to the reaction $2\text{NH}_3 \rightarrow 3\text{H}_2 + \text{N}_2$. For any given conditions, the per cent of dissociation will depend upon the temperature, the rate of flow, and the condition of the catalyst. Brief descriptions of various parts of the dissociator follow:

1. *Pressure Reducing Valve*—The ammonia vapor supply enters the dissociator through a constant-pressure reducing valve. This reducing valve is set for the minimum inlet pressure to the retorts (not to exceed 30 psi max) necessary to obtain the rated capacity of the dissociator with a back pressure of 5 psi at the throttling valve. A pressure relief valve located downstream from the pressure reducing valve will open if the pressure at this point exceeds the maximum of 30 psi. A pressure gage indicates the pressure at the above point.

2. *Dissociator Retort*—After passing through the pressure reducing valve, the ammonia enters the dissociator retorts which are filled with a catalyst. The dissociator retorts are located in a refractory-lined heating chamber, and heat is supplied for the dissociating process by means of nozzle mix burners which operate on "high-low" control. From the dissociator retorts, the disso-

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ciated ammonia goes to a water-cooled surface cooler and then passes through the flow meter and into the service line.

3. *Safety Alarm System*—In order for the ammonia dissociator to operate efficiently, the temperature of the dissociator retorts must be at the proper value. Too low an operating temperature will leave a high percentage of residual ammonia in the dissociator; on the other hand, too high an operating temperature will decrease the life of the alloy retorts and the catalyst. Temperature control

depends upon the specific size, source temperature, and equally important, its ability to cool the work below a certain minimum temperature to prevent oxidation. Another factor which has a significant bearing on the production capacity is brightness. This inherent factor, known as absorptivity or emissivity, varies from 0.12 for mirror bright to 0.3 for dull stainless steels and may sometimes be outside of this range.

Annealing to obtain certain physical properties requires that the steel be

mathematical expression derived from the following equations:

$$q = V \times D \times S (T_i - T_o)$$

where:

q = heat content of the metal, Btu,

V = volume, ft³,

D = density, lb/ft³,

S = specific heat,

T_i = final temperature, and

T_o = original temperature.

$$Q = 0.172 \times A \times e \left[\left(\frac{T_2}{100} \right)^4 - \left(\frac{T_1}{100} \right)^4 \right]$$

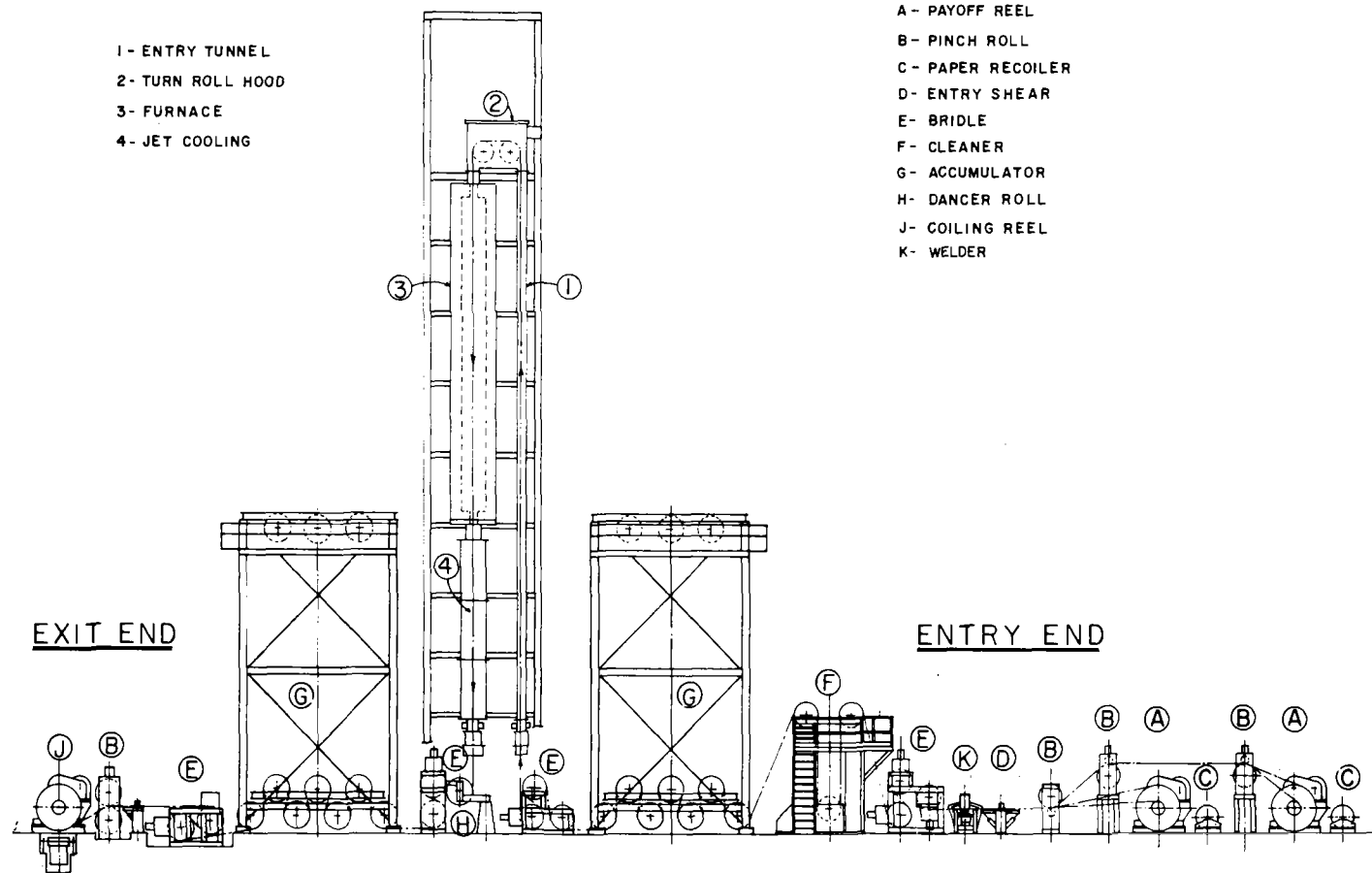


FIG. 1—Schematic Arrangement of Bright Annealing Line.

equipment is provided to hold the temperature of the dissociator at the desired operating value. The alarm system will operate if the temperature of the dissociator varies more than the permissible preset values. An ammonia pressure gage with high- and low-pressure contacts is provided with related alarm system. An air-operated alarm horn is provided in case the burner gas pressure fails or is shut off.

OPERATIONAL AND CONTROLLING FACTORS

Furnace Performance:

The capacity of a given furnace de-

heated above the recrystallization temperature or slightly higher, followed by a short soak and cool, or a cool immediately. To obtain maximum production, the furnace is operated at the maximum strip speed which will permit the strip to reach the desired temperature. Actual time to reach temperature sets the strip speed, and this time depends upon the source temperature. Furthermore, the time is directly proportional to the density, specific heat, and thickness of the strip, and is inversely proportional to the emissivity.

The time to heat a given strip to some temperature can be expressed by a

where:

Q = Btu/hr/ft², rate of radiation transfer,

A = area, ft²,

e = emissivity,

T_2 = absolute temperature of surroundings, and

T_1 = absolute temperature of work.

By working with a square foot of metal 1 in. thick and expressing time in seconds, we can obtain new values for q and Q represented by q^1 and Q^1 respectively.

$$\theta = \frac{q^1}{Q^1}$$

where θ is the required time in seconds to heat metal 1 in. thick to temperature.

$$\theta = \frac{q^1 \times t}{Q^1 \times e}$$

where:

- θ = required actual time, seconds,
- t = thickness of metal, and
- e = emissivity.

The heat-up time can be calculated from the ideal heating curve, Fig. 2.

4920 sec/in. of thickness. By increasing the source temperature to 1600 and 1800 F, the time to reach 1500 F can be reduced to 2950 and 1680 sec, respectively. These figures would indicate that the strip speed could be increased by factors of 1.7 and 2.9 with the above temperature heads. Unfortunately, these heating rates will never be obtained in a production furnace since the source temperature is dragged down at the

correlated with various surface finishes would enable one to judge better more representative values. Attention should be called to the fact that heating in a highly reducing atmosphere often increases the brightness resulting in lower emissivity values as the surface oxide is reduced or other surface contaminants are removed.

The apparent emissivity can be obtained by running a time-temperature curve on a representative specimen, or on the strip itself under actual operating conditions. From these curves, Fig. 3, and the ideal curve, the time for corresponding temperature increment can be read. The time read from the ideal curve must be multiplied by 1.5 to correct for the difference in specific heat for the chart and stainless alloy Type 430. The ratio of the ideal time to the actual time is the apparent emissivity.

Reference to the time-temperature curves, Fig. 3, shows that the two steels, 0.018 and 0.025 in. thick and having approximately the same emissivity coefficient, can be heated to the annealing temperature in the same time or strip speed. Further examination of the time-temperature curves shows that the heavier-gage metal was cooled at a faster rate by increasing the mass velocity. The cooling rate for a given gas temperature is proportional to the mass velocity of the circulating atmosphere raised to the 0.78 power. Calculations indicate the heat transfer capacity for the 0.025-in. thick strip is in the neighborhood of 30 Btu/ft²/hr deg F. The lighter-gage strip cooled 50 per cent slower, representing a transfer capacity of approximately 16 Btu/ft²/hr deg F.

The cooling rate of bright strip depends upon several factors, such as the emissivity, mass velocity of the impinging atmosphere, and gas temperature. For a given mass velocity and gas temperature, the cooling rate is inversely proportional to the emissivity. Thus, the emissivity has a direct bearing on the ability to cool as well as heat in a given furnace. The importance of knowing the apparent emissivity of the stainless strip cannot be overemphasized.

The present-day practice is to operate with a temperature head. If the apparent emissivity is something different from the value used in setting up production speeds, a change in the line speed will be necessary if the steel is to be annealed at the same temperature. When the emissivity is a higher value, the strip will heat to the annealing temperature

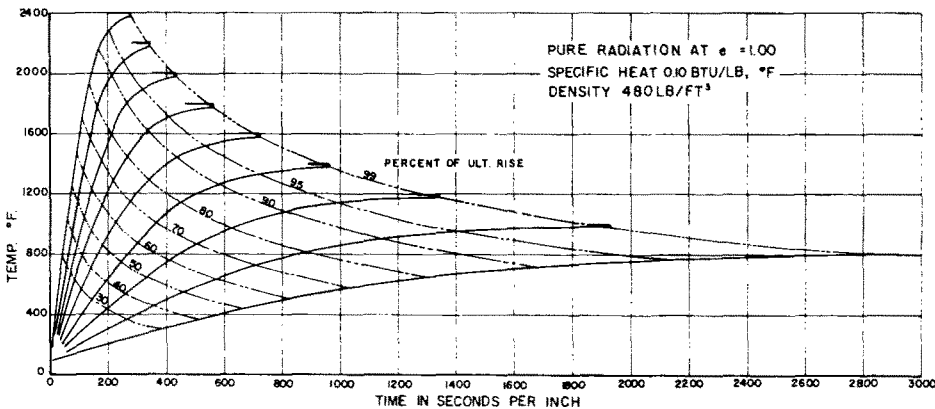


FIG. 2—Ideal Heating Curves.

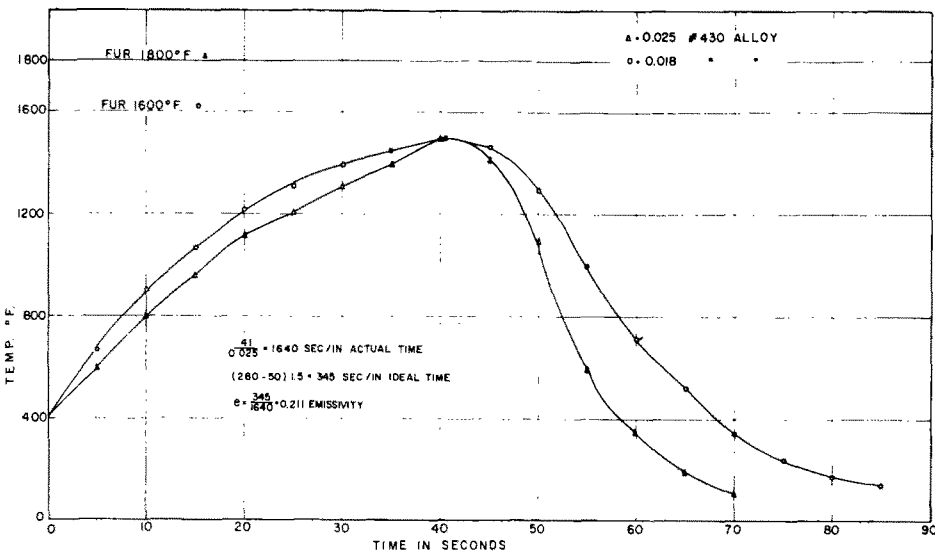
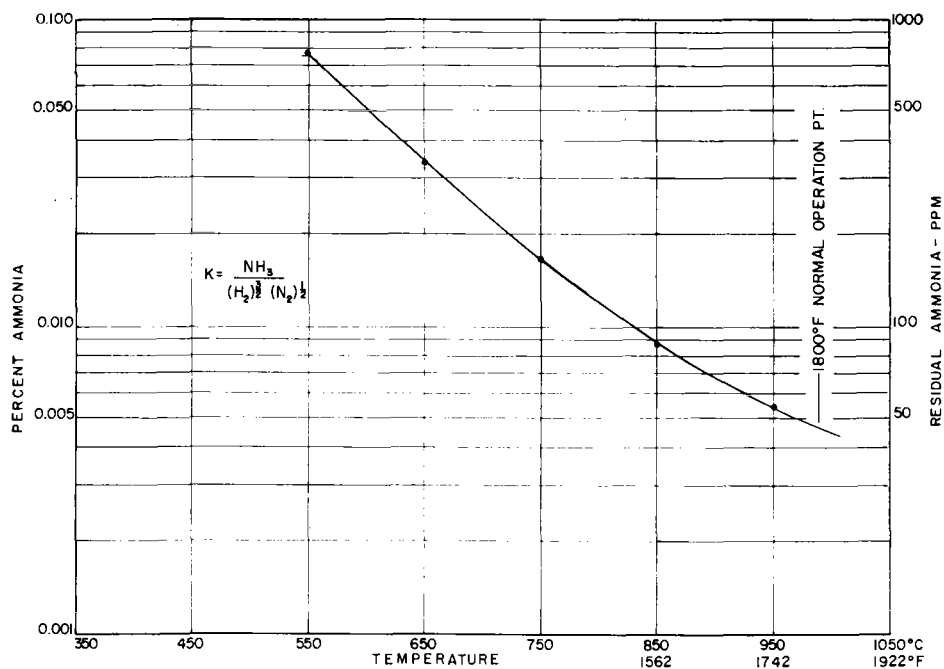


FIG. 3—Actual Heating and Cooling Curves.

Although these ideal conditions never exist in practice, the curves are very useful in estimating furnace strip speeds or furnace capacities. Reference to the curve indicates a time of 820 sec/in. of black body thickness is required to reach a work temperature equal to 99 per cent of the source temperature, 1500 F. For the curves to be applicable to stainless steel, it is necessary to correct for specific heat and emissivity factor. Assuming a specific heat factor of 1.5 and emissivity of 0.25, the heating time now becomes $820 \times 1.5/0.25$, or

entrance end by the cold strip. Another intangible factor which affects the heating time is the emissivity. Values can be obtained readily from published data but require judicious interpretation and use. For example, the terms used to designate the surface finish do not enable one always to select the proper values. Laboratory tests indicate that there is considerable variation in the emissivity due to surface finish, even for a designated classification, such as bright, mirror bright, and so on. The apparent emissivity values obtained from tests

FIG. 4—Residual NH_3 at Equilibrium Versus Temperature at One Atmosphere.TABLE 1—DEW-POINT VALUES RESULTING FROM DIFFERENT INLET LOCATIONS.^a

Position	Static Cool, 2400 ft ³ /hr			Cooling Hood, 2400 ft ³ /hr		
	Max	Min	Avg	Max	Min	Avg
1S ^b	43	56	50	50	63	53
1F ^c	53	66	57	54	65	58
2S ^d	44	60	52	52	65	55
2F ^e	55	64	60	56	72	60
Charge ^f	45	62	53	52	65	55
Discharge ^g	62	74	66	75	85	82

^a All readings are negative and deg F.^b 1S = first zone between shell and refractory.^c 1F = first zone furnace.^d 2S = second zone between shell and refractory.^e 2F = second zone furnace.^f Charge = entrance vestibule.^g Discharge = cooling hood.TABLE 2—DEW-POINT VALUES AFFECTED BY FLOW.^a

Position	Cooling Hood					
	2400 ft ³ /hr			3400 ft ³ /hr		
	Max	Min	Avg	Max	Min	Avg
1S ^b	50	63	53	50	57	53
1F ^c	54	65	58	55	62	58
2S ^d	52	65	55	57	71	64
2F ^e	56	72	60	64	75	67
Charge ^f	52	65	55	50	60	56
Discharge ^g	75	85	82	82	90	85

^a All readings are negative and deg F.^b 1S = first zone between shell and refractory.^c 1F = first zone furnace.^d 2S = second zone between shell and refractory.^e 2F = second zone furnace.^f Charge = entrance vestibule.^g Discharge = cooling hood.

in less time. In the aforementioned example, a time of 2950 sec/in. was required to heat stainless steel with an emissivity coefficient of 0.25 to 1500 F in a 1600 F source temperature. If the emissivity was 0.3 instead of 0.25 the time would have been only 2450 sec/in. thick-

ness. Conversely, a lower value of 0.2 would have resulted in a longer time or 3650 sec/in. of thickness. Thus, compensation in strip speed is required if the material is not to be under or over the desired annealing temperature. Either condition may result in higher hardness

values. It is doubtful if the emissivity for a specific metal finish will vary to this degree, but cognizance of this factor on annealing is of vital importance.

Atmosphere Requirements:

Two other problems associated with the bright annealing of stainless alloys are the extreme quality of the atmosphere required and nitrogen pickup. The atmosphere most commonly used is dissociated ammonia gas. However, purified hydrogen atmospheres may be employed where nitrogen pickup becomes a problem.

The quality of the dissociated ammonia gas depends upon the grade of raw ammonia used and dissociator performance. Dew-point reading and residual-ammonia determinations on the generated atmosphere are an indirect measure of the bright-annealing quality. When the best grade ammonia, (metal treating), is dissociated, dew-point values in the range of -70 to -80 F can be expected. Metal treating ammonia can be supplied to the following specifications: NH_3 content minimum 99.999 per cent, moisture 0.001 per cent, oil 3 ppm.

Residual ammonia in the dissociated gas atmosphere ranges from 60 to 100 ppm for good dissociator performance, and in some cases may be higher. Reference to the curve, Fig. 4, gives theoretical residual ammonia values for equilibrium conditions at various temperatures. For example, the charts show a value of -48 to -50 ppm for a temperature of 1800 F. Since ideal conditions are never obtained in actual practice, we can expect somewhat higher values from a dissociator. The pressure at which the dissociator operates also has a direct bearing on the residual. It increases in direct proportion to the absolute pressure. At 15 psig the residual would double, increasing to 100 ppm.

By passing the atmosphere through a molecular sieve dryer, both the dew-point and residual-ammonia values can be further reduced. Good dryer performance should lower the dew point to a value of -90 to -100 F, and the residual is usually reduced to less than 10 ppm. An atmosphere of this quality should present no problem in obtaining a bright metal surface unless adversely affected after being introduced into the furnace.

Some deterioration in quality is expected and does take place in the furnace. The degree depends upon several factors such as: (1) volume flow (ft³/hr), (2) location of the atmosphere inlet ports,

(3) venting of atmosphere, and (4) contaminates carried in with the strip, among others. A brief discussion of these factors is essential to understand how they influence bright annealing.

carried into the furnace which results in some degree of atmosphere poisoning. Aside from the above potential, a reaction of hydrogen with small traces of oxygen or oxides raises the dew point in

ensure the best possible atmosphere environment during the critical stage of cooling.

A study of Table 1 shows dew-point readings under actual production annealing of 430 alloy. The results compiled in the table represent conditions of operation over a long period of time at two different locations (static-cool and between two jet-cool sections). Dew-point readings were taken at six different locations along the length of the furnace. There was no significant difference in dew-point readings taken at the first five locations. Readings taken at the discharge location showed a marked improvement. The dew point changed from -66 to -82 F when the atmosphere was introduced into the cooling hood.

Flow was increased from 2400 to 3400 ft³/hr to see if this would have any effect on the dew point. Increasing the flow did not effect any significant improvement, as indicated in Table 2. Although the dew point in the second furnace zone and cooling hood was slightly lower, it is doubtful if this small change improved the bright annealing quality of the atmosphere.

The results of a study of the dew-point values operating at various furnace atmosphere pressures are recorded in Table 3. Over the pressure range studied, 0.1 to 1.8-in.-water column, there was little, if any, difference. It can be concluded that operating under the conditions of this study, pressure had no effect on the dew point at any of the various locations. Even though there was no obvious improvement in dew point, there were some operating advantages at the higher pressure levels.

Daily dew-point readings, as indicated in Figs. 5 and 6, compare day-to-day operation.

Increasing the flow did show a marked improvement when annealing the 200-series alloys. The metal surface was bright with no sign of a grayish cast. When the rate of flow was changed, the grayish cast would appear at the low flow and disappear in 15 min at the higher rate of flow. This would lead one to believe that flow was also a contributing factor in the bright annealing of these alloys.

The test was repeated with purified hydrogen. Dew-point readings for all practical purposes were the same as those for the dissociated ammonia gas atmosphere. At the low flow, a grayish cast was observed on the metal. When the flow was increased the metal came

TABLE 3—DEW-POINT VALUES AFFECTED BY PRESSURE.^a

Position	Static Cooling, 2400 ft ³ /hr								
	0.1 to 0.4-in.-Water Column			0.5 to 0.9-in.-Water Column			1.0 to 1.8-in.-Water Column		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1S ^b	45	56	50	45	54	51	46	54	55
1F ^c	52	62	58	54	62	58	52	63	57
2S ^d	44	58	49	47	60	52	49	60	54
2F ^e	55	63	60	52	70	61	56	65	60
Charge ^f	50	65	55	46	55	50	48	60	53
Discharge ^g	60	74	66	62	76	69	60	74	67

^a All readings are negative and deg F.

^b 1S = first zone between shell and refractory.

^c 1F = first zone furnace.

^d 2S = second zone between shell and refractory.

^e 2F = second zone furnace.

^f Charge = entrance vestibule.

^g Discharge = cooling hood.

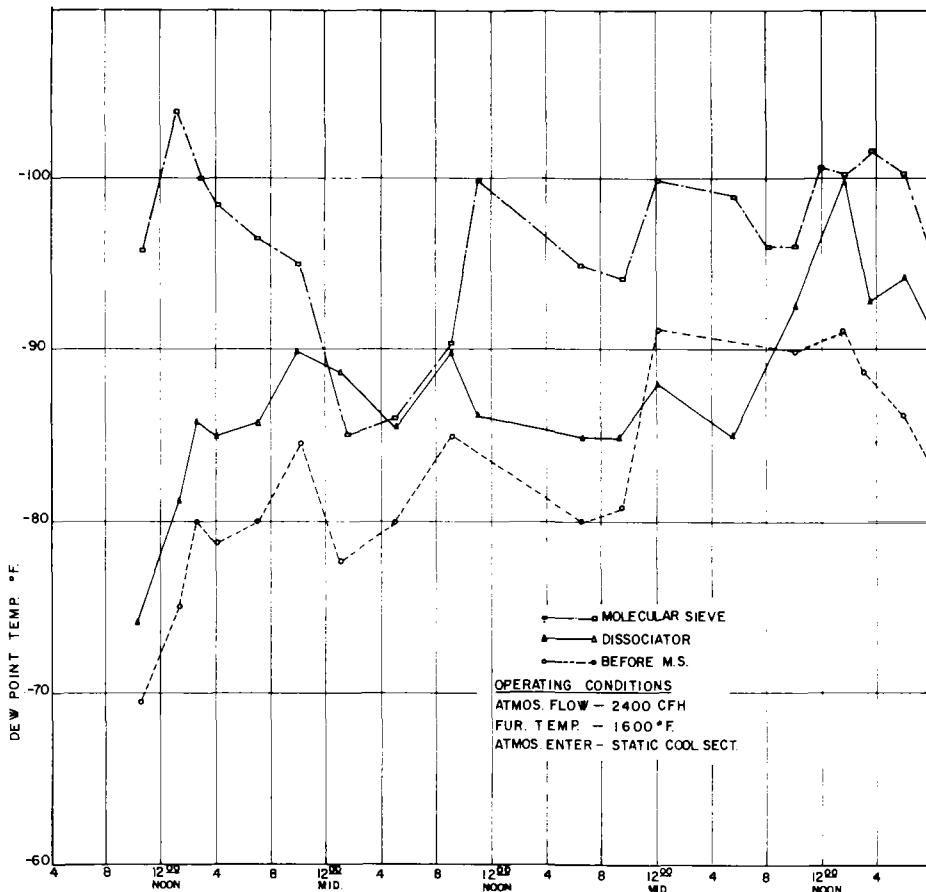


FIG. 5—Dew-Point Values of Dissociated NH₃ Gas to Furnace Versus Time.

An adequate flow of atmosphere is required to maintain a positive pressure inside the furnace and reduce to a minimum the backward diffusion of the atmosphere from the heating zone into the cooling hood. Even though the most stringent cleaning conditions are imposed on the strip, some contaminate is

the heating zone as compared to the atmosphere introduced. This reaction further impairs the bright annealing quality of the atmosphere. For these reasons it is desirable to introduce the atmosphere into the cooling hood. Atmosphere introduced at this location and vented at the charging end will

from the furnace bright. This performance substantiates, at least to some degree, the findings obtained with dissociated ammonia gas atmosphere.

Stainless alloys can be annealed successfully in protective atmospheres of dissociated ammonia gas and purified hydrogen. The former cannot be used when nitriding is a factor. Nitrogen pickup impairs the physical properties and lowers the resistance to corrosion.

atmospheres. It has been associated with inadequate purging or the lack of proper conditioning of the furnace when changing from dissociated ammonia gas to purified hydrogen.

PRODUCTION PROBLEMS

Leaks in Protective Atmosphere System:

If a bright, oxide-free surface is to be maintained, any leaks in the ammonia

head. This is done to increase production capacity by allowing faster line speeds. However, stoppages or slowing down of the line speed can cause high hardness in the straight chromium types and grain growth in chromium nickel types of stainless steel.

Cleaning Unit Problems:

(a) Trichlorethylene type—Since this type of unit basically removes oil, it is prone to leaving a dirty residue or smut on the surface.

(b) Alkaline cleaner type—This type of unit will remove the dirty residue or smut on the surface by a scrubbing action. However, if proper precautions are not taken, spots of the cleaning solution or minerals from the water may mark the surface after annealing.

Crystallized Surface:

Since the surface of the bright annealed product is not oxidized and pickled as in a conventional furnace, the finish should not be in a "finely divided state" (for example, result of grinding or coarse roll pattern), or it can result in a crystallized surface in the end product.

FABRICATOR PROBLEMS

Soldering:

Since the nature of the bright-annealed finish is such as to have less wetability for the flux, there is currently a soldering problem which requires some special production techniques and requires some development work.

Drawing:

The retention of the lubricant has been reported as more difficult by some fabricators, which has required some modification of lubricants and methods.

ADVANTAGES OF BRIGHT-ANNEALED PRODUCT

In summary, some of the advantages of a bright-annealed product are: (1) improved surface finish over a conventional annealed and pickled product, (2) reduced buffing costs, and (3) improved corrosion resistance.

In conclusion, bright annealing has made its place in the advancement of the art of producing stainless steel.

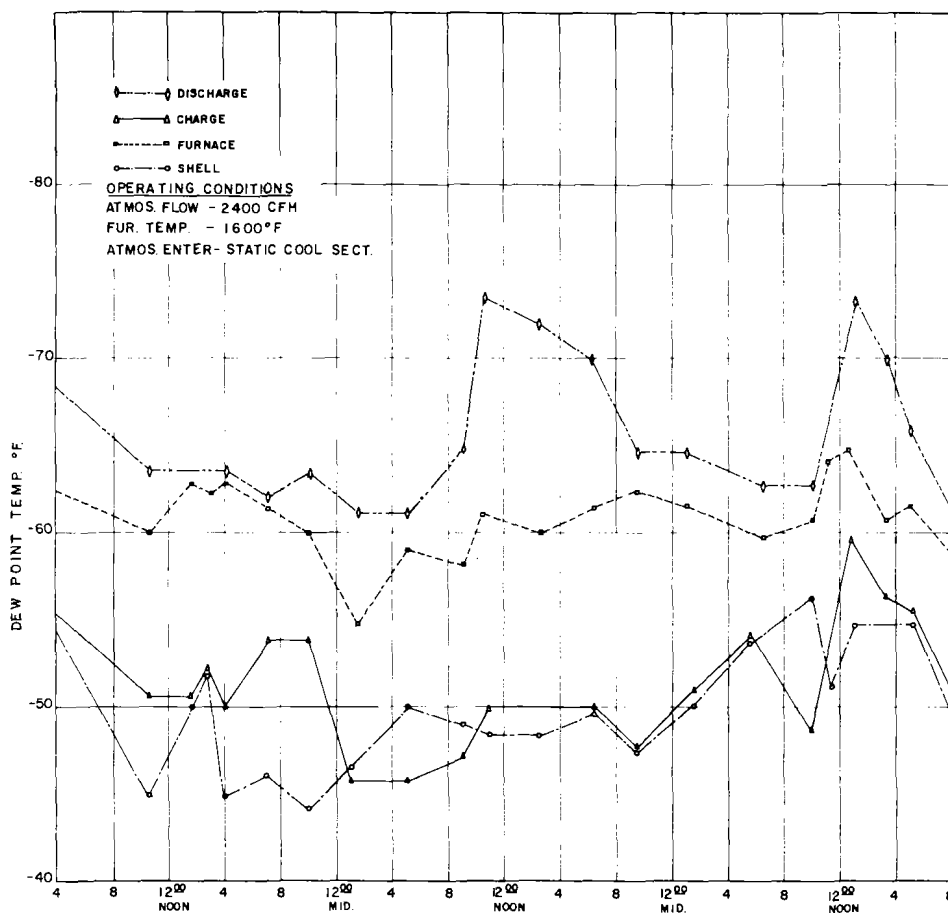


FIG. 6—Dew-Point Values of Atmosphere in Furnace Versus Time.

This is true especially where very thin strip (foil) is annealed.

Tests run on very thin coupons in dissociated ammonia gas atmospheres nitrified regardless of the residual concentration. Nitriding was experienced even when all the residual ammonia was scrubbed from the atmosphere. Nitrogen pickup can be prevented by annealing in purified hydrogen atmospheres. However, some precautions must be observed since nitriding has occurred in hydrogen

and dissociated ammonia system must be detected and isolated as quickly as possible. Some methods of detecting leaks are by means of sulfur tapers, dew-point analyzer, and visual testers at the various critical sections of the system.

Practice of Maintaining a Furnace Temperature Head:

Setting the furnace at a higher temperature than normally required for annealing is referred to as a temperature