# WILLIS HAVILAND CARRIER

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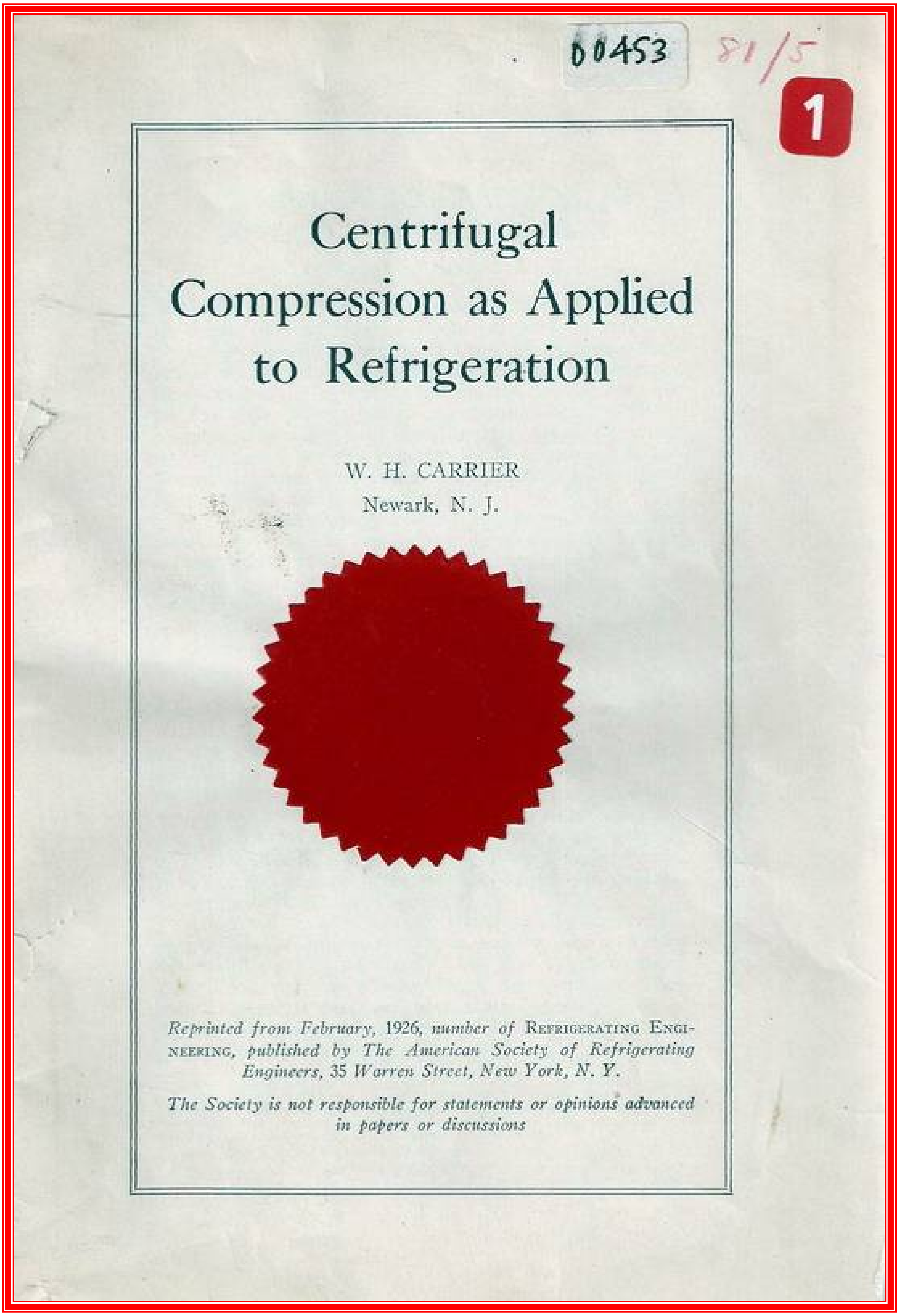
***By EurIng Brian Roberts, CIBSE Heritage Group***


THE UNITED STATES OF AMERICA
PASSPORT
DEPARTMENT OF STATE
To all to whom these presents shall come, Greeting:
I, the undersigned, Secretary of State of the United States of America hereby request all whom it may concern to permit
Willis H. Carrier
a citizen of the United States, safely and freely to pass and in case of need to give him all lawful Aid and Protection.
This passport is valid for use only in the following countries and for objects specified unless amended.
All Countries including Sweden and Denmark — Personal Business and Travel
The bearer is accompanied by
Given under my hand and the seal of the Department of State at the City of Washington the day of April in the year 1923 and of the Independence of the United States the one hundred and forty seventh.
PERSONAL DESCRIPTION
Age 46 years — Mouth medium
Chin round
Forehead broad — Hair grey
Eyes brown — Complexion dark
Nose large — Face oval
Distinguishing marks
Place of birth Angola N.Y.
Date of birth Nov 26 1876
Occupation Mechanical Engineer
SIGNATURE OF BEARER
No. 266937

**Willis Carrier passport, 1923**



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# Centrifugal Compression as Applied to Refrigeration


W. H. CARRIER
Newark, N. J.



*Reprinted from February, 1926, number of* REFRIGERATING ENGINEERING, *published by The American Society of Refrigerating Engineers, 35 Warren Street, New York, N. Y.*




***Refrigerating Engineering*, ASRE, February 1926**

PRO-59-2

# The Contact-Mixture Analogy Applied to Heat Transfer With Mixtures of Air and Water Vapor

By W. H. CARRIER,[1] NEWARK, N. J.

**The author derives and discusses the general contact-mixture formula for representing physical processes of heat transmission and fluid friction, and points out that the contact-mixture analogy serves directly and logically to correlate heat transfer with fluid friction. He compares the analogy with the conduction-viscosity theory and relates why the contact-mixture analogy explains all the phenomena connected with gas flow and heat transmission.**

HERETOFORE in literature, it has been customary from the time of Reynolds to analyze heat transfer and resistance to flow of gases by using an analogy to the flow of viscous fluids. While this method can be made to give a fairly good correlation of the phenomena of heating and frictional resistance of gases it is not representative of the actual physical process, and it is not easily applied, for example, to condensing and evaporating of water vapor into air except by the application of another analogy. The author believes it to be quite in line with modern physical thought to state that there can be no such thing as shear in a gas and therefore there can be no true viscosity. Also, probably, there is no true conduction in a gas as in a solid but only diffusion of molecules continuously in motion.

Any gas is made up of molecules having different velocities, i.e., different temperatures. The energy of the molecule (i.e., the absolute temperature) varies directly as the square root of its molecular velocity. Therefore, the average temperature of a gas composed of molecules having different molecular velocities is the average of the square roots of their respective velocities. We do not know actually what occurs when a gas contacts with a surface at a different temperature. We do know, however, that molecules in contact with a hotter surface are heated, i.e., their molecular velocity is increased and these high-velocity molecules are diffused and are mixed with other molecules of the gas which have not been so contacted. Whether they retain their identity as high-velocity molecules (which is to be doubted) or whether they impart a portion of their surplus energy to the adjoining molecules, which do not contact the surface, is immaterial as far as any study on heat transmission is concerned. The average of the square roots of the velocity, i.e., the total energy is the same whether they retain their energy or whether they impart part of their increased energy to other molecules.

In the process of pure heat conduction in gases, there is no mechanical mixture or disturbance due to gravitational effect (convection) but only intermolecular diffusion, which depends upon the various permanent properties of the gas and its transient condition. The rate of heat diffusion, however, is found experimentally, to obey exactly the analogous laws of heat conduction, that is, it is directly proportional both to the distance and to the temperature difference between two boundaries. In a steady state of heat flow, there is a temperature gradient precisely as there is a temperature gradient in a solid, although in the first case, the temperature gradient is due solely to material transportation, while in the second case, it is due to the passage of heat from one molecule to another.

These rather obvious and elementary statements are made in the preface in order that there may be no misunderstanding of the basis on which the problem is approached.

When a gas is forced to pass over a surface at relatively high velocity, as for example, between plates or through a pipe, the main stream of air is turbulent above certain critical velocities. However, at all velocities there are two nonturbulent films. The first, which is probably ultramicroscopic or molecular in thickness, is necessarily a dense film of adsorbed gas having approximately the density of liquid or, as some physicists claim, even greater than that of the liquid. This would appear to be a rather permanent film. The second, is a film or zone in which there is a laminar flow as distinguished from a turbulent flow, i.e., all the particles are moving in parallel lines. There is no mechanical mixture within this film. Particles pass from the surface film through the laminar film only by diffusion and heat is conducted only by the process of diffusion, just as though there were no motion whatever within the film since the actual motion is at right angles to the effective path of molecular diffusion. In this film, warmed (contacted) particles pass outward by diffusion while cold (uncontacted) particles, and also previously contacted particles, diffuse inward from the outer surface of the laminar film to the surface film. There is no sharp demarcation between the laminar nonturbulent film and the outer turbulent body of air, but a gradual increase of turbulence. However, from the standpoint of analysis it is convenient to consider a line of sharp demarcation. The thickness of the adsorbed film does not change with the velocity. The thickness of the laminar film, however, varies directly with the velocity and at a somewhat lower rate, i.e., at a fractional power of the velocity.

There is a definite temperature gradient in this laminar film

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[1] Chairman of the Board, Carrier Engineering Corporation. Mem. A.S.M.E. Mr. Carrier was graduated from Cornell University in 1901 and upon graduation accepted the position of research engineer with the Buffalo Forge Company. Five years later he became chief engineer. As the science of air conditioning developed under his guidance he saw the necessity for a separate organization and accordingly the Carrier Engineering Corporation was formed in 1915. Mr. Carrier is a member of the American Society of Heating and Ventilating Engineers and a past-president of the American Society of Refrigerating Engineers. He is the author of various scientific papers, among them a paper entitled "Rational Psychrometric Formulae" presenting the theory and practical data on which the art of air conditioning has been founded and in recognition of which he was elected to Sigma Xi in 1914. In 1934 Mr. Carrier was awarded the A.S.M.E. Medal for his work in air conditioning.

Contributed by the Heat Transfer Committee of the Process Industries Division and presented at the Annual Meeting of The American Society of Mechanical Engineers, held in New York, N. Y., November 30 to December 4, 1936.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until February 10, 1937, for publication at a later date. Discussion received after the closing date will be returned.





*Transactions ASME*, **1936**

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# A Review of Existing Psychrometric Data in Relation to Practical Engineering Problems

By W. H. CARRIER,[1] NEWARK, N. J., and C. O. MACKEY,[2] ITHACA, N. Y.

**The authors review and correlate available psychrometric data, and discuss the application of these data to engineering problems. They analyze and correlate existing data with reference to deviations of observed wet-bulb temperatures from those of true adiabatic saturation. The paper also includes a tabulation of revised psychrometric values in accordance with the latest physical data with correction factors for all normal variations of barometric pressures. The authors make an analysis and give a demonstration of the proper method of employing the psychrometric heat function previously defined as the "total heat less the heat of the liquid," and afterward referred to in psychrometry as "total heat." For this function the authors offer the term "sigma function," to distinguish it from the enthalpy or true total heat which includes the heat of the liquid.**

IN VIEW of the present wide employment of psychrometric data in various fields, and particularly in the field of air conditioning, and also in view of the fact that there have been numerous questions raised as to the limits of accuracy of existing data, it seems opportune to review and correlate, as far as possible, the past research in this field and to discuss the application of these data to engineering problems.

## Objectives of Paper

*First Objective.* The analysis and correlation of existing data with reference to deviations of observed wet-bulb temperatures from those of true adiabatic saturation.

*Second Objective.* Presentation of a tabulation of revised psychrometric values in accordance with the latest physical data with correction factors for all normal variations of barometric pressures. The purpose of this is to permit the ready use of standard psychrometric data or charts for any other barometric pressure without involved calculations. The latter is a device that has long been needed and is of particular value in accurate calculation of test data.

*Third Objective.* An analysis and a demonstration of the proper method of employing the important and useful psychrometric heat function, previously defined by Carrier in 1911 (1),[3] as the "total heat less the heat of the liquid," and afterward referred to in psychrometry as "total heat." For this function will now be offered the term, the "sigma function" to distinguish it from the enthalpy or true total heat which includes the heat of the liquid.

## Deviation of Observed Wet-Bulb Temperature From Temperature of Adiabatic Saturation

In the past 25 years, most of the engineering calculations involving humidity in air have been based on the psychrometric chart presented in 1911 by Carrier (1). The values given were based, not primarily, as many assume, on observed wet-bulb temperatures with a sling psychrometer, but on calculated values of adiabatic saturation. The paper (1) showed that experimentally the two values were in close agreement. However, test data presented in the original paper (1) in 1911 indicated two sources of deviation of the wet-bulb temperature from the temperature of adiabatic saturation. The first was the radiation factor which was indicated by the difference between the reading of an unshielded wet bulb and a wet bulb completely shielded from radiation, and the second was the difference between the reading of a radiation-shielded wet bulb and the observed temperature of adiabatic saturation, where the radiation-shielded wet bulb apparently gave the lower reading of the two. In view of the theory advanced, the latter variation was, however, thought at the time, to be due to an apparatus error.

Later observations conducted by Arnold (2) and by Dropkin (3) have shown the latter assumption to be incorrect and that it is not only possible, but in accordance with physical laws that the latter variation should exist. However, these two sources of deviation are in opposite directions tending to neutralize each other, and it has been proved that there is a definite air velocity where there is exact agreement between the wet bulb (not shielded from radiation) and the actual temperature of adiabatic saturation. Carrier's 1911 experiments (1) would indicate this velocity to be about 2000 fpm. Dropkin's test (3) would indicate it to be slightly over 1000 fpm. Arnold (2) would fix this velocity at about 500 fpm. Computations from his theory give a still lower value as shown in Appendix 1. The authors' present correlation would indicate it to be at an intermediate velocity

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[1] Chairman of the Board, Carrier Engineering Corporation. Mem. A.S.M.E. Mr. Carrier was graduated from Cornell University in 1901 and upon graduation accepted the position of research engineer with the Buffalo Forge Company. Five years later he became chief engineer. As the science of air conditioning developed under his guidance he saw the necessity for a separate organization and accordingly the Carrier Engineering Corporation was formed in 1915. Mr. Carrier is a member of the American Society of Heating and Ventilating Engineers and a past-president of the American Society of Refrigerating Engineers. He is the author of various scientific papers, among them a paper entitled "Rational Psychrometric Formulae" presenting the theory and practical data on which the art of air conditioning has been founded and in recognition of which he was elected to Sigma Xi in 1914. Mr. Carrier was awarded the A.S.M.E. Medal in 1934 for his work in air conditioning.

[2] Professor of Heat-Power Engineering, Cornell University. Professor Mackey was graduated from Cornell in 1926 with the degree of M.E. and for the next two years served as instructor of experimental engineering at the University. He then was made assistant professor of heat-power engineering and this year received a full professorship. He is the author of articles on psychrometric principles for the American Society of Heating and Ventilating Engineers and the American Society of Refrigerating Engineers. He is a member of the scientific fraternities Sigma Xi and Tau Beta Pi.

Contributed by the Heat Transfer Committee of the Process Industries Division and presented at the Annual Meeting of The American Society of Mechanical Engineers, held in New York, N. Y., November 30 to December 4, 1936.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until February 10, 1937, for publication at a later date. Discussion received after the closing date will be returned.



[3] Numbers in parentheses refer to the Bibliography at the end of the paper.

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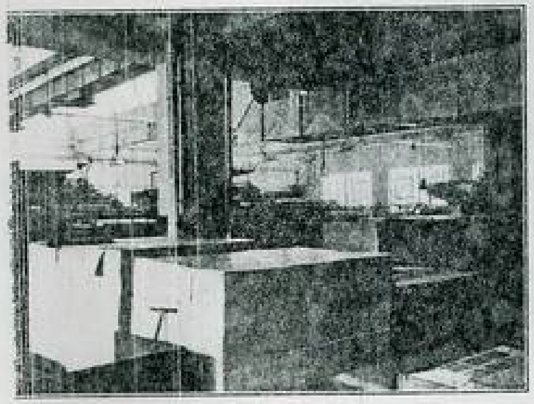
# Air Conditioning in the Printing and Lithographing Industry

By WILLIS H. CARRIER,[1] NEWARK, N. J., AND ROBERT T. WILLIAMS,[2] NEW YORK, N. Y.

LIKE other key industries, the great printing and lithographing industry shows a distinct trend toward concentration. With this trend, and the consequent need for ...ore careful technical control and greater standardization of prod...t and process, has come an increased realization of the need for ...r conditioning in the printing and lithographing industry.

For 20 years or more air conditioning has played an important ...rt in the textile industry, in the treatment and manufacture ...tobacco products, in the production of high-grade confections, ...d in a long list of other industries dealing with materials that ...e affected adversely by seasonal and daily weather variations. ...e equipment therefore necessary automatically to create and ...ntrol atmospheric conditions suitable to a given product or ...eration has undergone long development and has entirely ...ssed the experimental stage.

Even in the printing and lithographic industry, there are a ...mber of important and progressive plants in the country ...at have had complete air-conditioning equipment for about ... years. (See Fig. 1.) The wider use of air-conditioning ...uipment in the production of printed matter is therefore one of



...1 PRESSROOM WITH DISTRIBUTION DUCTS AND DIFFUSERS

...ation of relial... and standard equipment to the particular ... of this industry.

...he problem of air conditioning in printing and lithography ...lves itself into reproducing in those parts of the plant where ...itions of humidity, temperature, cleanliness, and air circu...n affect materials or processes, the natural atmospheric con...es that the trade has found by long experience give the ... results. This involves the control of regain by such hy...copic materials as paper and printers' rollers; the main...nce of a humidity sufficiently high to tend to prevent the ...ation of static electricity and sufficiently low to prevent ...terlogged" rollers and paper; the maintenance of tempera...s at which ink has the required viscosity and flow and rollers ...ight amount of "tack;" the elimination in so far as is com...ially practicable of floating dust; and the maintenance of ...fortable working conditions.

[1] President, Carrier Engineering Corp. Mem. A.S.M.E.
[2] Mechanical Engineer, Carrier Engineering Corp.

## MOISTURE IN PAPER RELATED TO STRETCH AND SHRINKAGE

In so far as concerns the regain of moisture by paper, which is the most serious and obvious problem confronting the printer, this control is secured by maintaining throughout all parts of the plant where paper is used or stored a fixed relative humidity. Temperature has practically no effect upon paper, but its moisture content is a function of the relative humidity of the surrounding air, the amount varying for different grades of paper. (See Table 1.)

TABLE 1 EQUILIBRIUM MOISTURE CONTENT OF PAPERS UNDER VARIOUS CONDITIONS OF RELATIVE HUMIDITY

*(From Bulletin No. 1, Lithographic Technical Foundation)*

| Kind of paper: | Number of sheets | Relative humidity of atmosphere 35% | 45% | 55% | 65% |
|---|---|---|---|---|---|
| Offset, % | 18 | 4.04 | 5.06 | 6.08 | 7.09 |
| Sized and super-calendered, % | 6 | 3.55 | 4.43 | 5.30 | 6.17 |
| Machine finished, % | 4 | 3.48 | 4.50 | 5.52 | 6.53 |
| Casein-coated one side, % | 10 | 3.50 | 4.45 | 5.37 | 6.27 |
| Casein-coated two sides, % | 2 | 4.67 | 5.61 | 6.57 | 7.55 |
| All kinds, % | 40 | 3.81 | 4.78 | 5.75 | 6.71 |

*(From Tests Made by C. D. Sudermeister, Cumberland Mills)*

| | Humidity 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
|---|---|---|---|---|---|---|---|---|---|
| Max moisture, % | 4.53 | 5.95 | 7.03 | 7.90 | 8.70 | 9.45 | 10.20 | 11.39 | 12.90 |
| Min. moisture, % | 2.00 | 3.10 | 4.02 | 4.70 | 5.28 | 5.88 | 6.52 | 7.27 | 8.27 |
| Avg. moisture, % | 2.87 | 4.12 | 5.07 | 5.87 | 6.58 | 7.31 | 8.09 | 9.05 | 10.38 |

This variation in the regain of paper with varying relative humidities exercises an important influence on printing and lithographic processes. The moisture content of paper affects its size. The amount of stretch or shrinkage varies with different stocks, but may be said to be from 0.311 to 0.55 per cent across the grain and from 0.056 to 0.25 per cent with the grain under a change in relative humidity of 35 to 65 per cent. When it is considered that the allowable variation in register in process presswork is rather under 0.02 in., or 0.045 per cent of a 44 by 64-in. sheet, it will be seen that certainly a variation of more than 5 per cent in the relative humidity of a pressroom will destroy register.

The center of a large pile of paper is under heavy pressure and is very nearly impenetrable. Even fire will not get to it. Moist air attacks the edges first, and the fibers swell. Not being able to stretch uniformly the stock stretches at the edges, which gives the sheet a curl or wave and makes it difficult or impossible to feed accurately. This also occurs when moist stock is piled in a dry atmosphere. The edges of paper will not curl or wave if the air is allowed to circulate uniformly over the whole surface of the individual sheets.

The moisture content of paper also seriously affects both its strength and printing quality, and these qualities are again in ratio to the relative humidity of the surrounding air.

Paper is ordinarily received from the mill with a moisture content of from 3 to 4 per cent, but inasmuch as this may be the equilibrium percentage corresponding to anywhere from 20 to 40 per cent relative humidity, depending upon the kind or make of paper, it is impossible to try to keep the atmosphere of the plant in equilibrium with the incoming stock. From every practical standpoint in operation and economy it is desirable to maintain a fixed relative humidity in the plant and to condition the paper up to this point prior to running it on the presses.

## PRINTING ROLLERS, HUMIDITY AND TEMPERATURE

Passing from paper to the other hydroscopic substances used by the printer there are the rollers and also the glues and pastes used in the bindery. Rollers, being made of glue and glycerin, are particularly sensitive to both moisture and temperature. Under fluctuating conditions they swell, shrink, and crack, the free glycerin oozes out, and they become distorted in shape. However, as rollers may be manufactured to function at any given

Mechanical Engineering, Chicago. May 1925.

# Temperatures of Evaporation of Water into Air

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00457

## A Report of Experiments Made to Determine the Laws Governing the Deviation of The Actual Temperature of Evaporation from the Theoretical

By W. H. Carrier[1] and D. C. Lindsay,[2] Newark, N. J.

It was first shown in the paper entitled Rational Psychrometric Formulas,[3] presented before the Society at the Annual Meeting of 1911, that a fundamental equation of heat balance may be established between any evaporating liquid and the surrounding atmosphere, and that eventually a constant equilibrium temperature is reached, which can be altered only by changing the total-heat relation between the liquid and the atmosphere. This equilibrium temperature, commonly termed the "wet-bulb temperature," is determinable by a thermometer, the bulb of which is kept wet by the evaporating liquid. The wet-bulb temperature throws a very interesting light on the fundamental laws involved in all commercial evaporative processes, and the effect of the wet-bulb temperature upon human physical comfort has a great popular interest.

The experimental data herein presented prove conclusively that the temperature of evaporation is not indeterminate, but has a very definite limit which in practical application is very closely approximated and which is dependent upon the ultimate equilibrium of heat conditions.

Although it has been recognized that observations of wet-bulb temperatures are in error with respect to the theoretical temperature of equilibrium, exact data as to the amount of this error and its variation relative to temperature and effective velocities of air have heretofore been only approximated to. During the past four years the authors have conducted exhaustive experiments with special equipment at Cornell University and at the Case School of Applied Science. The purpose of the experiments has been, first, to show that under ideal conditions permitting true adiabatic saturation, i.e., maintaining a constant total-heat relation during saturation, the wet-bulb temperature is actually the temperature of equilibrium represented in the heat-equilibrium equation; and secondly, to show how, and to what extent, the wet-bulb temperature, observed under ordinary conditions, varies from the theoretical equilibrium temperature.

### The Equations of Heat Balance and Relative Rates of Diffusion

Of two general methods which have been proposed for the study of laws underlying the equilibrium temperature in an evaporating liquid which obtains its heat of vaporization from the surrounding atmosphere alone, the first involves the equation expressing the increase in the heat of vaporization as equal to the decrease in the sensible heat of the atmosphere from which the heat is extracted. This equation of heat balance is:

Latent heat absorbed = Sensible heat lost

or

$$r'(w' - w) = (C_{pa} + C_{ps}w)\,(t - t') \qquad [1]$$

where

$r'$ = latent heat of vaporization per unit weight of vapor at the resultant temperature $t'$

$w'$ = final weight of vapor per unit weight of gas into which the liquid is evaporating

$w$ = initial weight of vapor per unit weight of gas

$C_{pa}$ = mean specific heat of the gas between temperatures $(t - t')$

$C_{ps}$ = mean specific heat of the vapor between temperatures $(t - t')$

$t$ = initial temperature of the gas

$t'$ = final temperature of the gas, vapor, and liquid.

From this the theoretical temperature of equilibrium may be definitely located if the initial temperature and moisture content and the final moisture content of the gas are known.

The second method analyzes the rates of heat flow—the sensible heat flow to the wet bulb from the surrounding atmosphere—due to temperature difference, and the corresponding rate of outward heat flow, due to the evaporation of the liquid and its diffusion into the surrounding atmosphere.

Equations expressing the balance of rates of flow are:

Rate of moisture diffusion from unit area of liquid surface per unit time:

$$\frac{dw}{Ad\theta} = k'(e' - e) \qquad [2]$$

where

$dw$ = weight of liquid evaporated per unit time $d\theta$

$A$ = area of evaporating surface

$k'$ = coefficient of moisture diffusion per unit difference in vapor pressure of liquid and vapor pressure in the atmosphere

$e'$ = vapor pressure of liquid

$e$ = vapor pressure in atmosphere.

Rate of heat diffusion through film to liquid surface:

$$\frac{dq}{Ad\theta} = h(t - t') \qquad [3]$$

where

$dq$ = heat diffused per unit time $d\theta$

$A$ = area of surface

$h$ = coefficient of heat diffusion per degree difference in temperature of liquid and atmosphere

But $dq = r'dw$, where $r'$ = latent heat of vaporization corresponding to temperature $t'$; therefore

$$\frac{dw}{Ad\theta} = \frac{h}{r'}(t - t')$$

and

$$(e' - e) = \frac{h}{k'r'}(t - t') \qquad [4]$$

According to the law of gaseous mixtures the weights of the two component parts of a mixture are in proportion to the products of their respective pressures and their specific weights. So in a mixture of water vapor and air:

$$w = \frac{Se}{P - e}$$

where $w$ = weight of moisture per pound of air

$S$ = specific weight of water vapor compared with air

$e$ = vapor pressure

$P$ = barometric or total pressure of the mixture.

$$e = \frac{Pw}{S + w}$$

Substituting for $e$ in Equation [4],

$$\frac{Pw'}{S + w'} - \frac{Pw}{S + w} = \frac{h}{k'r'}(t - t')$$

At temperatures below 150 deg. fahr. where $w$ and $w'$ are small, this equation may be written

$$\frac{P}{S + w}(w' - w) = \frac{h}{k'r'}(t - t')$$

$$r'(w' - w) = \frac{h}{k}(t - t') \qquad [5]$$

where $k = k'P/(S + w)$.

[1] President, Carrier Engineering Corporation, Newark, N. J. Mem. A.S.M.E.

[2] Physicist, Carrier Engineering Corporation.

[3] Trans. A.S.M.E., vol. 33 (1911), p. 1005.

Presented at the Annual Meeting, New York, December 1 to 4, 1924, of The American Society of Mechanical Engineers. Abridged.



*Mechanical Engineering,* **May 1935**

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W. H. Carrier
July 5, 1944

00458

ENGINEERING EDUCATION

(First Lecture)

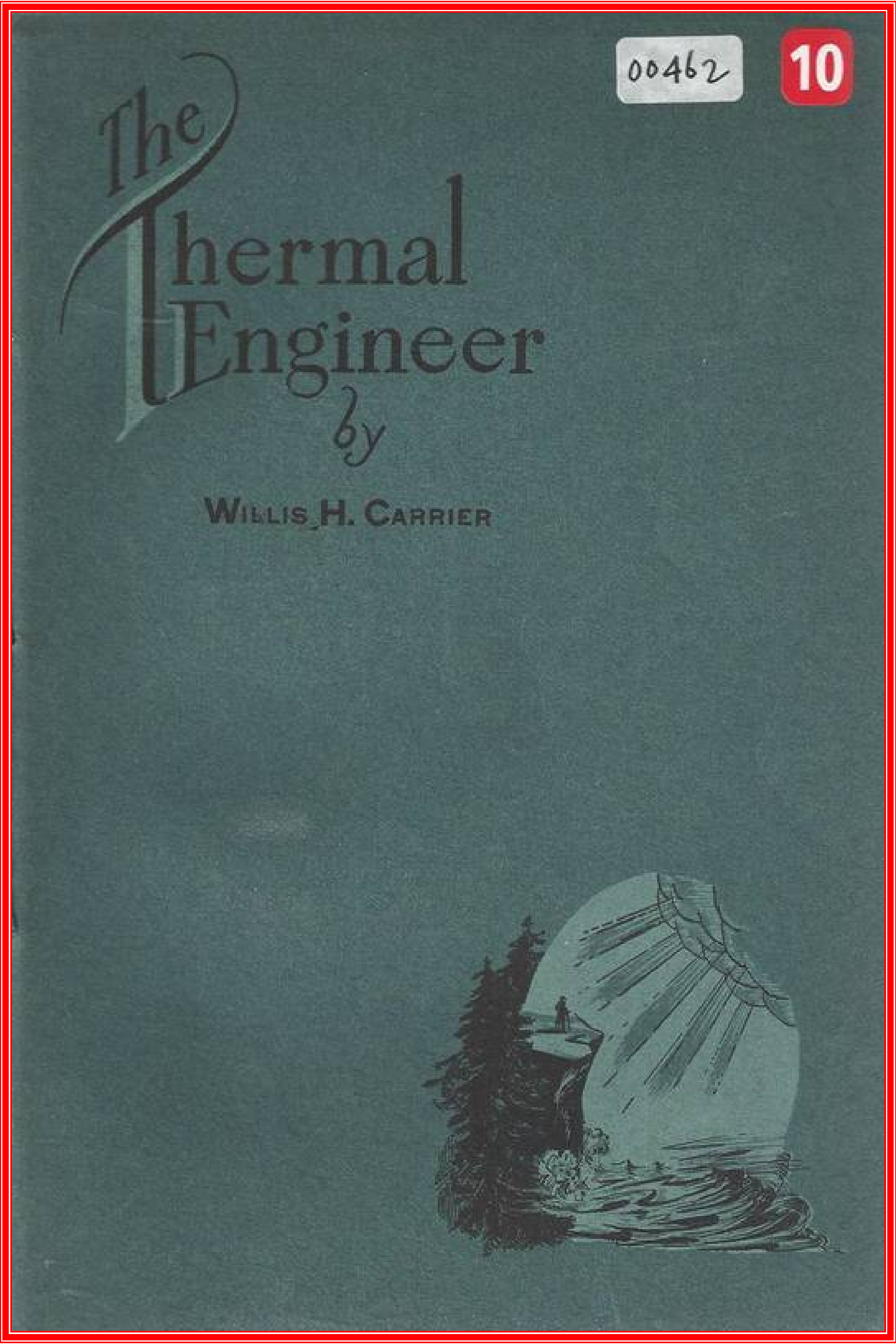
Continual Progress in Education:

The generally accepted idea is that the engineer gets his education in high school and college. If this accepted idea were correct, the quality of our engineering would be extremely poor. Unfortunately, too often this same idea is prevalent among the more recent graduates and I have known men of excellent natural ability in our own organization who required ten years of experience in the field to discover that this was not true. Generally, however, the engineering graduate discovers this fact for himself in the first two or three years. If he is a conscientious and thorough-going person of a type that will ultimately succeed, he sets about either consciously or unconsciously to further his education. I did not say "complete his education" because if he is a person who will continue to advance in his profession, contrasted with one who "goes to seed" and becomes a casualty; he will realize that his education never will be completed. He will continually progress throughout his useful lifetime. My hope is that you may take this viewpoint and as a result strive continually to advance your education, whether it be in pure engineering, management or salesmanship. It is my sole reason for addressing you on this subject.

Defects in Elementary Engineering Education -- (Should Teach Approach to Knowledge):

I shall start out by telling you that I consider the character and methods of education which most of you have received is unfortunate. With few exceptions, the quality of teaching, from grammar school all the way through college, is not only poor but in the majority of cases has the wrong objective as well as the wrong approach. From my own viewpoint, which I may say is also

**Willis Carrier Engineering Lecture Notes, 1944**




*Willis Carrier's ASRE Presidential Address,* **December 1927**

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## AMERICAN ENGINEERING AND TECHNOLOGICAL ADVANCES DURING WAR-TIME.

*THE accomplishments of American engineers which had such decisive influence on bringing World War II to a victorious end, have received little attention in the editorial columns of* THE ENGINEERS' DIGEST *during the past five years. The paper shortage has compelled us to devote our regrettably few editorial pages to reporting almost exclusively on technical developments which have taken place in enemy and neutral countries, and on which practically no information could otherwise reach our readers in Great Britain and all over the British Empire.*

*The splendid cooperation between the American Office of Scientific Research and Development and the British authorities, and between a large number of American and British engineering firms engaged in the development and production of materials and weapons of war, has covered the most urgent and vital common interests of both countries. A certain amount of information on American developments has reached the British industry, also through various British trade papers in the form of reprints from the American trade papers to which some British firms and libraries subscribe.*

*The interest of British engineers in obtaining, in concise form, exhaustive information on the work and achievements of their fellow engineers in the United States, has been obvious but has not yet been satisfied. In devoting the January and February, 1946, issues of* THE ENGINEERS' DIGEST *to articles on important American engineering developments, we are attempting to meet this interest. In doing so, we are fully aware of the limitations imposed upon us by the very little space of mere fifty-two pages allocated for editorial contents of these special issues. The magnificent accomplishments of the greatest industrial country of the world, would require and deserve editorial treatment of hundreds of pages for each of the subjects covered in our survey. Therefore some of our articles have to deal with a narrow field of a broader subject, while others include numerous references to further sources of literature. Articles which for lack of space cannot be published in the two special issues on American war-time engineering developments, will appear as a special section in later issues of our journal.*

*Under the chairmanship of Dr. Alexander Klemin, of New York University, the internationally known aeronautical expert and writer, prominent engineers of highest reputation cooperate in deciding on the editorial policy of the American edition of* THE ENGINEERS' DIGEST. *The names of these fine representatives of American engineering are listed on the inside cover page of this issue.*

*We are proud and happy that these distinguished representatives of American technical knowledge have joined the Editorial Advisory Board of our journal. Their active cooperation has been of invaluable help in compiling our special issues on American developments. It also shows the gratifying interest of American engineers in the interchange of international technological information as well as in promoting the feelings of friendship and appreciation between American and British engineers.*

*A further aim of* THE ENGINEERS' DIGEST *has been to counteract narrow specialization and to promote the broadening of engineering knowledge. In a recent book by twelve prominent members of the Harvard faculty, appointed by President Conant and headed by Dean Paul H. Buck, drastic changes are recommended in the curriculum of Harvard and in the whole American educational system. The book, the result of the work of two years and many distinguished minds, recommends a balanced programme. It grants the inevitability of specialization in a technological society such as ours, but deprecates the present tendency in both high schools and colleges toward narrow specialism. It is great satisfaction to receive such high confirmation that we have been working in the right direction.*

*J. E. PAJZS.*

*New York, December, 1945.*

**Summary of Articles from *The Engineers Digest,* 1945**

# The Control of Humidity and Temperature as Applied to Manufacturing Processes and Human Comfort.

(Paper No. 324)

*By Willis H. Carrier.*[1]

The control of atmospheric conditions within an enclosure with reference to temperature, humidity, and cleanliness is termed "Air Conditioning."

The importance of this field of engineering has of late years become widely recognized, not only in engineering circles, but by the public at large. Perhaps this is best evidenced by the fact that the forthcoming edition of the Encyclopedia Britannica will contain a chapter devoted exclusively to air conditioning. Such chapters are already found in some of the leading engineering hand-books.

It has long been recognized that relative humidity is an important factor in the manufacture and processing of certain hygroscopic materials such as textiles. Since the normal relative humidity in textile factories is nearly always lower than that desired, various means have for many years been provided to increase the humidity by artificial means.

On the other hand, there are industries which require a definite and unvaried humidity so that at some periods the normal quantity of moisture in the air must be increased, and at other times lowered. Among such industries may be mentioned the manufacture of confectionery, the processing and weaving of artificial silk, and the printing and lithographing industry.

Other industries require not only a constant relative humidity, but also a fairly uniform temperature. An example of this is seen in the modern automatic wrapping machines, used for wrapping chewing gum, food products, confectionery, and machine made cigarettes, which require exact conditions of heat and moisture in order to function satisfactorily without frequent adjustments.

In the manufacturing and processing of most hygroscopic materials there is usually one or more stages in the process in which moisture has to be removed from the material. In all such products which are not in themselves soluble in water, this is usually accomplished by air drying.

In a very large portion of them, in order to avoid injury to the products which require temperature and humidity control, the rate of moisture removal must be controlled with accuracy in certain stages of the process, while at the end of the process of drying it may be extremely important to control with

1) Assisted by an Advisory Committee appointed by the American Society of Heating and Ventilating Engineers as follows:

| | | |
|---|---|---|
| Prof. A. C. Willard. | O. W. Armspach. | H. W. Ellis. |
| W. L. Fleisher. | H. P. Gant. | F. C. Houghten. |
| S. R. Lewis. | C. P. Yaglou. | L. A. Harding. |
| F. R. Still. | | |

***Paper No. 324*, ASHVE, 1929**

# Comparison of Thermodynamic Characteristics of Various Refrigerating Fluids

## With Reference to Their Adaptability for Both Positive and Centrifugal Compression

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and
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Newark, N. J.



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*Refrigerating Engineering,* **ASRE, June 1924**

# RATIONAL PSYCHROMETRIC FORMULAE

## THEIR RELATION TO THE PROBLEMS OF METEOROLOGY AND OF AIR CONDITIONING

By Willis H. Carrier

ABSTRACT OF PAPER

In many industries such as the manufacture of textiles, food products, high explosives, photographic films, tobacco, etc., regulation of the humidity of the atmosphere is of great importance. This paper deals with the subject of the artificial regulation of atmospheric moisture, technically known as air conditioning. It gives a theoretical discussion of the subject in which formulae are developed for the solution of problems. These formulae are based upon the most recently determined data and in order to establish a logical basis for the presentation of these data and the derivation of the formulae, the principles governing atmospheric moisture are reviewed and the present methods of determining atmospheric humidity are discussed.



*ASME Transactions,* **1911**

# THE TEMPERATURES OF EVAPORATION OF WATER INTO AIR

## AN EXPERIMENTAL DETERMINATION OF THE LAWS GOVERNING THE DEVIATION OF THE ACTUAL TEMPERATURE OF EVAPORATION FROM THE THEORETICAL

BY

W. H. CARRIER
Mem. A.S.M.E.

AND

DANIEL C. LINDSAY

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
29 WEST THIRTY-NINTH STREET, NEW YORK

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# ENGINEERING EDUCATION

A SPECIAL luncheon conference on engineering education was held in connection with the 1936 Annual Meeting of the A.S.M.E. at Midston House on Dec. 3. Papers dealing with three phases of this important subject were presented by W. H. Carrier, N. E. Funk, and H. O. Croft, and are printed, substantially in full, below. Each author brought numerous points of importance to educators and engineers. The more outstanding ones follow.

Emphasis was laid by Mr. Carrier on the fact that engineering education, in most colleges, places a premium upon memorizing instead of stimulating independent thinking and that it is deductive rather than inductive. Futility of repeating the teaching of the same principles in different engineering courses where the student did not grasp the relation was stressed by Mr. Funk, who also drew upon his own experience to show how the same principles when taught differently in separate courses remained as separate ideas for some time after graduation. Professor Croft commented upon the growing tendency to lower the requirements for graduation from high school below the minimum that would serve as a foundation for an engineer's education and proposed the formation of a national committee to study this problem thoroughly and prepare a high-school curriculum that was planned more particularly for those students who intended to enter professional schools.

## PRINCIPLES *Versus* CURRICULUM *in* MEMORIZING FACTS *and* THEORIES

By W. H. CARRIER

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AS SHOWN by its results, present practice in engineering education seems to be faulty in several respects. It appears to be designed almost wholly for the students who acquire all their knowledge from books or from their teachers' efforts, while it neglects the smaller but more important group who can go beyond the boundaries of existing knowledge.

The present system, instead of stimulating the creative imagination so necessary for the successful engineer, seems to discourage or dull it. It allows students to accept facts blindly instead of training them to understand and to reason for themselves. In spite of this training, engineers with exceptional ability and strength of character do develop the ability to think independently and advance beyond the boundaries of existing knowledge by retaining and developing their own creative imagination.

We find engineering students who have a superficial knowledge of many things with minds loaded with partly digested facts but generally with a very poor grounding in the basic physical laws on which engineering is founded or a thorough understanding of them. The chief reason for the state of affairs we find in our engineering schools is that engineering knowledge and its application have multiplied to such an extent that to begin to cover the field adequately, by the time-honored methods with segregated subjects, in a four-year course is impossible. The schools have attempted to meet the demands of the public, of employers of engineers, and of faculty members with some particular bent. The result is a greatly overcrowded curriculum with far too much attention to specific applications of engineering, too advanced specialization in various individual subjects, and, more particularly, *insufficient coordination* of allied subjects. The main purpose of an engineering education, the understanding of principles, and the use of mental tools of the profession, is thus overlooked and defeated.

### THINKING A LOST ART AMONG ENGINEERING STUDENTS

The student is expected to learn more and more in a given time, and the courses must be made "easy" so that he can accomplish the work laid out in the curriculum. To obtain high or even passing marks, he must rely on memory, as this is the easiest and most primitive process. He cannot be trained to think nor would he have time if he tried. He becomes the skin of a sausage which is to be stuffed with meat, and many of our educational products are just about that. They have not been trained to think nor have they acquired confidence in their own mental processes outside of their ability to memorize and to gather facts from the printed page. Thinking, to their minds, is an outmoded process; and they dislike it. They want to be given formulas in which their data can be placed, and by which the required results can be mechanically computed. They want to be slide rules. They think this is engineering. The surprising thing about much of our technical education is that the product is so good in spite of the education rather than because of it.

Another failure of the engineering schools from the employer's standpoint is that he finds difficulty in selecting a man on the basis of his standing in college. The student with apparently the very best standing may be merely a memory machine and, therefore, of little value to the employer subsequently. Wastage in hiring engineers, especially for technical positions, is great.

So far in this discussion, I have, perhaps, been overcritical. I do appreciate the great amount of valuable teaching that is done, but I think that, in many cases, our objectives are wrong. Improper emphasis is placed on the things that are of the least value to the engineer at the expense of those that are vitally important. Perhaps one of the reasons for my rather extreme attitude in this matter of engineering education is my own personal experience in three phases, precollege, college, and postcollege education. This experience, together with subsequent dealings with graduates of many of our engineering institutions, is the basis of my criticism, and, from it I hope to make constructive suggestions. For this reason, I may be pardoned if I recite some incidents that are based on my personal experience.

In my own education, I feel that I was extremely fortunate in not having it regimented in my early years. I went to a two-room district school; then, to a small-town high school.



*Mechanical Engineering,* **undated**