The origins of pneumatic steelmaking are traced from early operating practices based on the beginning concepts of this steelmaking technique put forth by Sir Henry Bessemer. Development of oxygen jet steelmaking in both its top and bottom blown forms is reviewed. The fundamentals of gas jet behavior are emphasized including the importance of physics, mechanics and chemistry and their role in steelmaking reactions involving slag, gas and metal. The vital combination and the continuing interaction of fundamental science and engineering development in the evolution of pneumatic steelmaking technology are emphasized. The frontiers of knowledge and the areas for further study of jet steelmaking processes are outlined. Future evolution of the application of jets in steelmaking are considered from the perspective of past and present.

It is a privilege and a very special honor to have been offered the opportunity to present the 1980 Howe Memorial Lecture. The annual Howe lecture is held as a memorial to Henry Marion Howe, a distinguished scientist, teacher and metallurgical engineer, whose career has had and continues to have a substantial positive impact on the development of the entire field of ferrous metallurgy.

Robert D. Pehlke is Professor of Metallurgical Engineering and Chairman of the Department of Materials and Metallurgical Engineering at the University of Michigan. He holds a B.S. in metallurgical engineering from the University of Michigan, an S.M. and Sc.D. in metallurgy from the Massachusetts Institute of Technology.

Dr. Pehlke began his teaching career at the University of Michigan as an assistant professor in 1960, moving up to associate professor in 1963, and professor in 1968. In 1973 he was made chairman of the department.

From 1955 to 1956 Dr. Pehlke was a National Science Foundation Fellow. The following year, he was a Fulbright Scholar. He is a registered professional engineer, a consultant for numerous firms, and has done work in metallurgical research at the General Motors Research Laboratories and the Ford Scientific Laboratory.

Dr. Pehlke is a member of the Iron and Steel Society of AIME and served as chairman of the Process Technology Division in 1976–77. In 1979 he was named a Distinguished Life Member of ISS-AIME. He chaired the editorial board for the AIME Monograph Series on Basic Oxygen Steelmaking and has been a major contributor to the ISS Continuing Education Program.

He is also a member of The Metallurgical Society of AIME and chaired the Publications Committee (1964–66) of the Iron and Steel Division. In 1976 he received the Extractive Metallurgy Science Award of TMS-AIME. Dr. Pehlke was named a Fellow of the American Society for Metals in 1976 and is co-editor of the 1964 ASM seminar volume on Computers in Metallurgy. He received the American Foundrymen’s Society Steel Division Best Paper Award in 1970 and 1979, and the Malleable Iron Division Award in 1971. He is co-author of the AFS Monograph on Computer Simulation of Solidification. Dr. Pehlke is a member of the Iron and Steel Societies of Japan, Germany, and London. He has served as National President of Alpha Sigma Mu and is a member of Tau Beta Pi, Sigma Xi, New York Academy of Sciences, National Society of Professional Engineers and the American Society for Engineering Education.

Dr. Pehlke is author of the text Unit Processes of Extractive Metallurgy and is author or co-author of over one hundred technical publications.
I have selected the subject of pneumatic steelmaking for today's lecture for two reasons: first, because my own metallurgical career to date has been heavily involved in this type of steelmaking, and secondly, because this subject is appropriate to the memory of Henry Marion Howe who extensively treated the industrial processes and related chemistry, as for example in his outstanding text, "The Metallurgy of Steel." My university studies in metallurgical engineering were initiated coincidently with the first commercial oxygen steelmaking heat at Linz, Austria in 1952. Furthermore my graduate studies and subsequent engineering teaching and practice have been closely coupled with various forms of oxygen steelmaking and the related chemistry of the processes. I also find in the writings of Henry Marion Howe a unique understanding and exposition of concepts, nearly all of which are valid in modern pneumatic steelmaking, despite the fact that his commitment of pen to paper on these subjects occurred in 1890, 9 decades ago.

The subject of pneumatic, or more specifically in recent times jet or oxygen, steelmaking is not new to the Howe Memorial Lecture series. In the relatively recent past the subject has been considered by Bernard Trentini in 1968 and by John McMulkin in 1973 and the role of interfacial reactions in steelmaking was reviewed by Gerry Derge in 1967. More recently the Iron and Steel Society has published a five volume monograph on Basic Oxygen Furnace Steelmaking in which the characteristics of the oxygen steelmaking process are considered over the full gamut of its application from fundamental chemistry to the design and operating requirements for a commercial plant. Also in the monographs series, the threads of history are touched upon. In this lecture, I wish to go beyond these previous presentations to consider the development of pneumatic steelmaking, using this broad generic term, and to couple these developments, many of which have been documented by Dr. Howe, with the present in an effort to come to some judgments on the areas where new knowledge must be developed and to attempt to foretell what the future evolution of these processes can be. In doing so, I will place an emphasis on the patent literature, a reference source which should receive greater engineering and operating attention. However, in this brief review all of the contributions cannot be covered but the historical evolution will be emphasized.

EARLIEST BEGINNINGS OF PNEUMATIC STEELMAKING

Until the mid 1850's, the manufacture of steel was carried out principally by the crucible process. This process was costly and could produce only a few pounds of steel at a time and the principal form of iron and steel produced was either as pig iron or wrought iron. The needs of civilization were manifesting themselves in demand for steel in large quantities. A response came with development of the converter process for pneumatic steelmaking which represented a giant step in production and brought the world into the steelmaking age.

Prior to this point in time approximately 125 years ago, and extending back to antiquity, the production of steel was in extremely small batches. Several forms of steel production evolved, all of which depended upon achieving a suitable carbon and oxygen balance such that the final product had a slight excess of carbon giving rise to the strengthening characteristic of steel. The reduction of iron ore to produce ferrous metals has been dated back to about the 14th century B.C. Subsequently, and perhaps by accident, the direct production of steel could be achieved by reducing iron ore with carbon in the presence of an excess of carbon. If sufficient excess carbon were present and the carbon content of the various portions of sponge iron produced were sufficiently high, then the resulting product could contain sufficient carbon such that during continued reheating and some oxidation, a redistribution of carbon would occur to provide a relatively homogeneous product which then could be shaped into a steel implement. The reheating process could also be carried out in the presence of excess carbon as a carburizing process. Some evidence exists from as early as 1000 B.C. showing case hardening to produce hardened edges for iron weapons and tools.

The crucible process, which consists of melting wrought iron in clay crucibles to which carbon has been added for the purpose of increasing the carbon content of the metal, was known and practiced in early times. Subsequent to the middle ages, steel production was practiced in the western world both by the cementation process which was a solid state carburization of wrought iron, and by the crucible process which treated the product of the cementation process by melting and casting it to provide a homogeneous and relatively inclusion-free product.

BESSEMER STEELMAKING

Continuing industrial development and the requirements for transportation brought incentives for higher tonnage production of steel. This need was answered by the development of pneumatic steelmaking. William Kelly in Eddyville, Kentucky, and Henry Bessemer in England independently invented the original pneumatic process, which involved blowing air through a bath of molten pig iron to oxidize the carbon and silicon and produce steel. The vessel described in Bessemer's first patent is shown in Fig. 1. Bessemer secured patents in England and in the United States in 1856 and although Kelly did not apply for a patent until 1857 he was able to show that he had worked on this concept as early as 1847. It is noteworthy as well that work in this area was simultaneously going on under the direction of Joseph G. Martien in Newark, New Jersey. The basis for this process was that the oxidation of the principal impurities in liquid pig iron (silicon, manganese and carbon) occurred prior to the oxidation of iron and that sufficient thermal energy would be released by the chemical oxidation to permit the blowing of cold air through the molten iron to produce liquid steel without external heat. Concurrent with development of this process was the concept of Robert Mushet to add material containing iron, carbon and manganese, i.e. spiegeleisen, which re-carburized the iron providing