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Changes in analytical chemistry corresponding to the stage of industrial development

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Summary. The industrial application of analytical chemistry is characterized by its mutual dependence on the stage of technical development. This relation and the changes that have taken place during the last 150 years are demonstrated by way of examples. At the beginning of this period analytical chemistry had only to serve as supplier of analytical data for the investigation of chemical systems, and today at the end of the time observed a great variety of analytical methods produce and supply in special fields most of the information for control and regulation systems of technical processes.

Introduction

At the beginning, the title of this paper needs some explanations. This paper should be regarded as a short contribution to *applied* analytical chemistry. Typical for its *industrial* application is especially its mutual dependence on the stage of industrial development. This relation and the changes that have taken place during the last 150 years shall be demonstrated by way of examples out of metallurgy, which can be looked at as inorganic chemistry at high temperatures.

Why metallurgy? Metallurgy belongs to one of the primary industries. The progress of it is directly connected with the development of process-adapted analytical methods. The variety of process routes and products implies inorganic and organic questions, and includes materials present in three states of aggregation. Solving the analytical problems multi-element analyses have to be performed and multi-method concepts have to be applied.

Changes in historical view

In this respect several periods of industrial analytical application have to be distinguished which are characterized by very different aims dependent on the stage of technical development.

1839–1870

About 150 years ago analytical chemistry had only to serve as a supplier of analytical data for the investigation of chemical reactions and the kinetics of physico-chemical processes. An interesting example to this point is the fundamental research work of Robert Bunsen [1], well-known as one of the founders of emission spectral analysis, about the chemical reactions in a blast furnace and the role played by the different gases during the reduction process. By these results Bunsen enlarged essentially the fundamental knowledge about the blast furnace process and was the first scientist who dealt with questions of process optimization in this field.

In connection with these investigations R. Bunsen invented many apparatuses needed for sampling out of chemical systems and the analysis of gases.

At this point it should especially be stressed that these analytical data coming out of a chemical process had *not* been used for process control and could not be used for it due to the experimental difficulties and the time-consuming methods. But it was, of course, also a question of intention and the lack of an analytics-promoting philosophy. This period was mainly ruled by empirism.

1870–1910

The second period of applied analytical chemistry in metallurgy began about 1870. The first chemical laboratories were built in order to get some or some more information about the composition of raw materials and solid fuels, and to determine the contents of a few elements in final products of the different processes.

The values obtained from the same steel grade or of the same "quality" covered a wide range as e.g. shown in Table 1. The variation of the chemical composition of cast steel axles in 1874 [2].

Table 1. The chemical composition of cast steel axles in 1874 [2]

Element	Range of analytical results obtained, wt. %	Tolerable values, wt. %
C	0.29 –0.70	0.5–1.0
Si	0.07 –0.28	≤0.25
Mn	0.09 –0.37	
P	0.049–0.090	≤0.1
S	0.062–0.201	≤0.2
Cu	0.02 –0.42	≤0.25
Ni	0.01 –0.11	
Pb	0.01 –0.02	
As	0.003–0.114	

* Dedicated to Prof. Dr. Dr. h. c. Hanns Malissa as meritorious founder of the Symposium on Philosophy and History of Analytical Chemistry

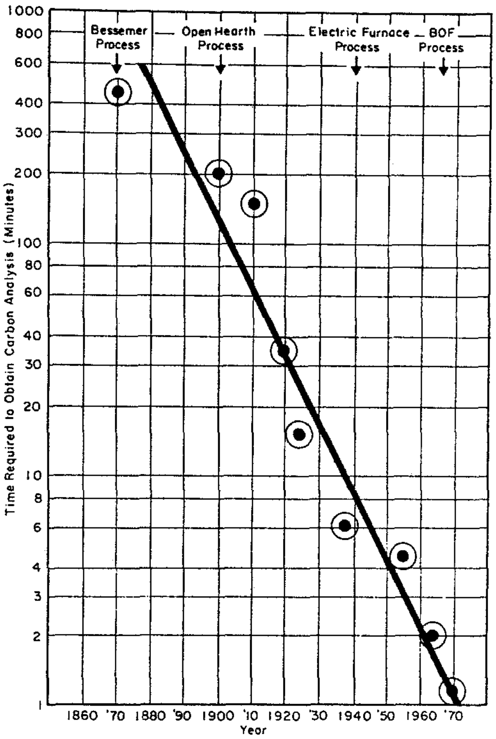

Fig. 1. The historical development of time needed for the determination of carbon in steel [4]

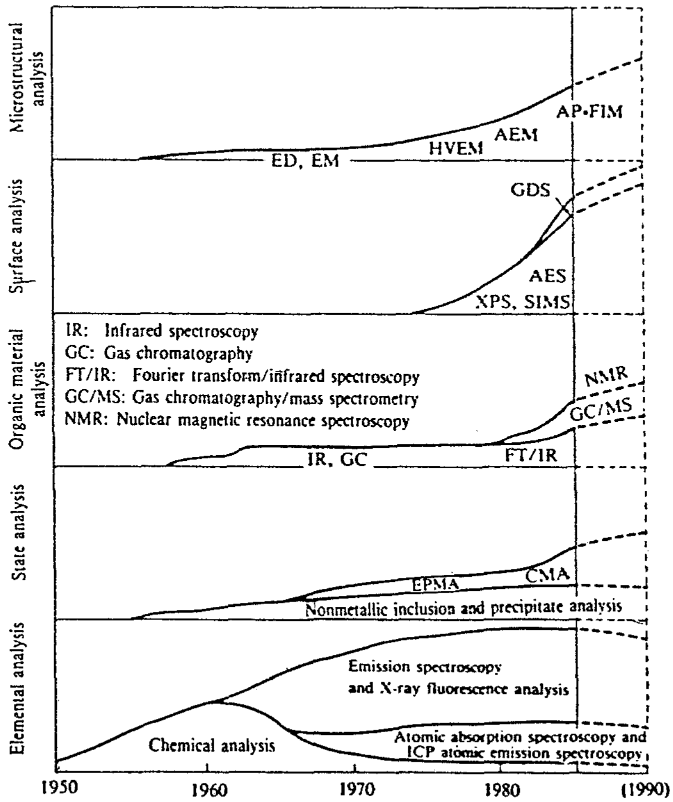

Fig. 2. Changes in analytics for ferrous materials [10]

These results demonstrate that in those days the requirement in quality could be fulfilled by analytical methods as a retrospective view. They were not yet fit for purposes of process control. But nevertheless the need for cooperation and progress in special analytical fields was obvious (1883), the first chemists' committees were founded, and the first interlaboratory tests were performed in order to improve the comparability of results (1888) [3]. The sensitivity and the reproducibility of the methods had been increased.

1910–1940

Beginning during the first decennium and consequently during the second decade of this century the analytical demands grew exponentially. This development was stimulated by the need of product control, the need for a more comprehensive knowledge in materials science and the better understanding of the processes. During this period of rapid development in metallurgy took place: the widespread application of the open hearth and the invention of the electric furnace processes. These facts meant a great challenge for the analytical chemist, and more and more rapid analytical methods became necessary and available.

The mutual dependence can be impressingly explained by the development of carbon determination (Fig. 1). The time needed went down from hours to several minutes by using rapid combustion methods [4]. At that time carbon was the most important element because mainly carbon steels had been produced. But even when producing alloy steels chemical methods were sufficient for process control because the process time lasted several hours.

It should be mentioned that at the beginning of this period the first environmental analyses (e.g. SO_2 and dust in the air; phenol in waste water) had been performed, and at the end of this period the use of mathematics for the interpretation of analytical results began [5]. Analytical chemistry did no longer play the role of a kitchenmaid, it had become essential for the technical and economical results and the prosperity of industry [6].

Table 2. Historical survey of the characteristic changes in a special field of applied analytical chemistry

Period	Years	Characteristics
1839–1870	ca. 30	analytical data for process research and process optimization
1870–1910	40	Chemical analysis of some raw materials, fuels, and single elements in final products
1910–1940	30	Complete analysis of all raw materials and products; analysis for production control purposes
1940–1960	20	Spectrometric methods for rapid production control; improvement and standardization of analytical methods
1960–1989	ca. 30	multi-method concepts; process analysis; automatization
	150	

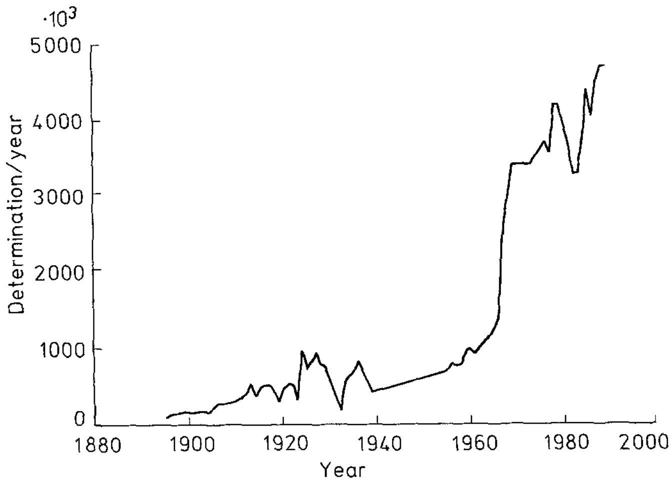

Fig. 3. Increase of analytical determinations of a steel works laboratory in historical view

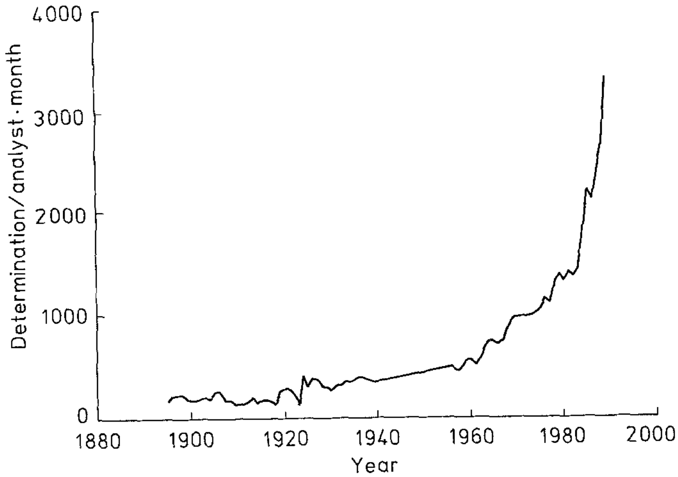

Fig. 4. Development of the analytical productivity of a steel works laboratory

1940–1960

During the next two decades one can observe the improvement of analytical methods in many fields and the standardization of methods; the production of (certified) reference materials arose. Due to many factors, e.g. increase of (steel) consumption and of costs, the time postulated other processes and other analytical methods. Emission spectral analysis entered the chemical laboratories, at first only for special problems as spectrographic method, i.e. using photographic plates as indicating system, and afterwards as spectrometric principle with photoelectrical measurement [7]. Emission spectrometry became the essential presupposition for the development and the worldwide application of the blast oxygen steelmaking processes. Without this analytical principle no rapid steel production at low costs would be possible.

1960–1989

The last period to be looked at can be described as period of multi-method concepts and the beginning of real process analysis [8]. New aspects entered analytical chemistry which now needs a philosophic basis [9]. It is the time of a strong motivation and fascination which is due to the fact: With solving one analytical problem at least two new problems arise.

The problems of process control and product analysis in connection with quality assurance could no longer be solved only by emission spectrometry: X-ray, atomic absorption, ICP and glow discharge spectrometry have become of great relevance.

Surface and phase analysis and the investigation of auxiliary materials are today of special importance. At the end of this historical excursion it must be stated that a great variety of methods is applied in this industrial field [10] (Fig. 2), that there is a steady increase of the importance of analytics, and that analytical chemistry is never finalized. Furthermore, it has to be mentioned that analytical systems today produce and supply most information [11] for control and regulation systems of the processes in question.

The whole result of this analytical development strongly following the lines of technical requirements and the industrial stage can be summarized in Table 2 and in two figures, which show an example for the increase of analytical determinations of a steel works laboratory (Fig. 3) whereas the steel production raised from about 0.3 to about 4.2 million tons with a maximum of 7 million tons in the seventy years and the analytical productivity expressed as determination per analyst (Fig. 4).

Education in applied analytical chemistry

In view of the historical development and the state-of-the-art in analytical chemistry [12], and its importance for the technical progress the education in modern analytical chemistry [13] must imply the teaching of applied analytics [14], e.g. methods of process analysis and its economic relevance [15].

This would be part of the basic purpose of analytical education, namely, following H. Malissa [16]: To create means and tools to be able to distinguish between true and false and to find the conformity of the evaluated data from a sample with the collective in question (sample as "synholon").

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