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MECHANICAL POWER[1]

I have selected for my address to-night the subject of power—mechanical power—because I believe even workers in science do not fully appreciate the extent to which our present-day civilization is dependent upon this product of science. It is only within a century, however, that mechanical power has become so great a factor in our daily lives.

A century is a very short period in comparison with the number of years man has inhabited this earth. Up to within about a century ago, man truly obeyed the biblical injunction to earn his bread by the sweat of his brow, for the great majority of men and women were slaves or serfs. The Greek and Roman civilizations rested on slavery. Athens had 400,000 slaves to 100,000 free citizens. The industries of Rome were run almost entirely by slave labor.

In the latter days of the Roman Empire, water power became sufficiently developed to compete with slave labor, and "water mills" gradually displaced slave labor in the bakeries, in irrigation and in sawing marble. During the middle ages, mechanical power from water wheels and wind mills was applied in grinding grain, in metallurgical processes and in mining and quarrying, but to a limited extent only.

By the end of the seventeenth century, the coal-mining industry reached appreciable proportions in England and on the continent. As the mines were worked to greater depths, the pumping of water from them became a serious problem. The pumps were operated by horses—as many as 500 horses being employed at one mine for this purpose. The expense of pumping became so great that many mines were abandoned. This situation was relieved by the invention of the steam-pumping engine—that of Savery in 1698 and of Newcomen in 1705.

Economic conditions at this time—the first half of the eighteenth century—are indicated by the average wages of a skilled workman in England, about $2.40 a week. Wheat varied from $1.00 to $1.50 a bushel. Thus, the carpenter or mason could earn only from two to three bushels of wheat for his week's work.

Before the eighteenth century, man used only a few elements of machines and crude combinations of them. In the latter part of that century occurred those great inventions in spinning and in weaving where the skill and intelligence of the workman were transferred to

[1] Address of the retiring president of the Nebraska Chapter of Sigma Xi on May 15.

machinery operated by mechanical power. The nineteenth century witnessed the development of machinery with greater than human skill and with but little less than human intelligence, many times multiplying man's productiveness through the utilization of mechanical power.

Mill machinery was first operated by water power while the steam engine was first developed to pump water from coal mines. It is therefore not surprising that the first proposal to operate a mill by steam power comprised a steam boiler and engine to convert the heat energy of coal into mechanical energy, a pump to convert the mechanical energy into potential energy of water and a water wheel to convert the potential energy of the water back into the mechanical energy for driving the machinery. The crank connecting rod mechanism was soon invented, however, affording a means of converting reciprocating into rotary motion and thus utilizing more directly the mechanical power of the reciprocating steam engine.

In recent years, we have gone back in many instances to the original proposal, using, however, in place of the water pump, piping and water wheel, an electric generator, transmission line and electric motor between the source of mechanical power and the machinery where the mechanical power is to be utilized. I mention this simply to emphasize the fact that while electricity is often a very convenient means of transmitting power, it is not a primary source of power and it must in general be converted into mechanical power or into heat before it can be utilized.

In 1869, the first year that power statistics were collected by the Bureau of the Census, the mechanical power for the industries of the United States was obtained only from water wheels and from steam engines and boilers fired with coal. The internal combustion engine had not yet reached a practical form. The installed primary power in the manufacturing industries was 1,130,431 horsepower in water wheels and 1,215,711 horsepower in steam engines. In mining and quarrying, the installed primary power was 2,247 horsepower in water wheels and 109,111 horsepower in steam engines. Steam power was used exclusively on the railroads and on ships, amounting to about 3,300,000 and 1,070,000 horsepower, respectively.

In 1869, there was thus available in the United States about 6,827,000 horsepower, of which about 16 per cent. was water power and the remainder steam power. The population was about 38,116,000 people, somewhat less than 0.2 of a horsepower being therefore available for each person.

In the fifty years from 1869 to 1919, remarkable increases occurred in the horsepower available in prime movers. There have been further advances since that date, but the following approximate figures, based partly on the census data for 1919, will give some idea of the tremendous amount of mechanical power now at the service of mankind. In manufacturing, the 2.3 million horsepower of 1869 has grown to more than 29.5 million. In mining and quarrying, the 111 thousand horsepower has increased to over 6.8 million. On the railroads, the horsepower has increased from 3.3 million to sixty-five million or more. The estimated horsepower of the United States Navy is about ten million, and commercial shipping and private yachts and motor boats will account for another ten million horsepower. On the farms, animal power only was used in 1869, amounting to less than ten million horsepower; in 1919, while the animal power had more than doubled, mechanical power to the extent of about 20 million horsepower was employed. Probably four million horsepower are installed in isolated plants in non-industrial establishments. In 1869, central power stations did not exist for furnishing electricity for lighting, railways, etc.; in 1919 they had an installed capacity of twenty million horsepower, of which about ten million, used in industrial plants and on farms, is included in preceding figures. Conservatively, 345 million horsepower in internal combustion engines are installed in the seventeen million automobiles, motor trucks and tractors in use in this country, of which about six million horsepower is already accounted for as employed in agriculture.

The grand total of these figures is over five hundred million horsepower available for a population of 105 million people, or about five horsepower for each man, woman and child. Since a man's power is less than one tenth of a horsepower, this is equivalent to more than fifty slaves for each inhabitant of the United States.

The ancient Greek triremes had ten marines, twenty sailors and 170 rowers. Compare this with the airplane carrier Saratoga, launched a few days ago, having a crew of 179 officers and 1,695 men and propelling machinery of 180,000 horsepower. This power is equivalent to that of two million galley slaves.

Of the five hundred million horsepower available in 1919, about eight million, or less than 2 per cent., was water power. The remainder had for its primary source of energy, coal, petroleum or natural gas, except about one tenth of one per cent. in windmills on farms. The United States Geological Survey has estimated that the amounts of energy contributed by the four main sources of energy in the United States in 1919 were in the following proportions: Coal, 77.3 per cent.; petroleum, 13.6 per cent.; natural gas, 4.3 per cent.; water power, 4.8 per cent.

The first three sources are limited and will some day be exhausted. It is often assumed that water power will then be developed to take their places. The potential water power resources of the United States, even with water storage, are estimated by the United States Geological Survey to be only 34,818,000 horsepower, or less than one fourteenth of our present installed capacity. Evidently, water power can never take over the burden now borne by coal, oil and gas. Unless science and engineering develop wider applications of what are now minor sources of mechanical power, the human race must some day return to work.

There is a tendency for the man on the street to shrug his shoulders and say that the scientists will discover other sources of energy before that time—that the energy of the atom will be unlocked, that electricity will be taken from the air. To a person not well grounded in the physics of energy and matter, such propositions do not appear any more wonderful than, for example, the radio. But the fact that Mr. E. W. Rice, Jr., of the General Electric Company, estimates a revenue of several million dollars annually for the sale of electric power to operate radio equipment, is an indication that the laws of thermodynamics are not contravened by this device. Although I am inclined to question whether the second law of thermodynamics is of as broad application as generally stated, I regard as very improbable the unlocking of stores of energy from sources other than those already used to some extent.

Some research should be devoted to the development of what are now minor sources of mechanical power. However, the exhaustion of our natural resources of coal, oil and gas is not immediate. Petroleum in quantity will probably be available for two or three hundred years and coal for two or three thousand years. Greater efforts should be exerted to improve the combustion of fuels, the production of mechanical power from the heat of combustion and the utilization of mechanical power by machinery of various kinds.

Although coal will be available for many years, the better grades for metallurgical and power purposes are approaching exhaustion. Methods of utilizing the poorer grades must be developed to higher degrees of efficiency. One method of accomplishing this is through reducing the amount of inert nitrogen in the air supplied for combustion. There is thus needed an economical process for producing oxygen which may be mixed with atmospheric air or used in a nearly pure state.

After combustion has taken place, the energy exists as heat, and improved means should be sought for converting heat energy into mechanical energy. It has been customary to analyze power plant performance by the first law of thermodynamics, but such an analysis should preferably be based upon the second law in order to show where the greatest inefficiencies exist in the process of converting heat into mechanical work. The first law analysis heretofore made is misleading in this respect. For example, according to the first law, no loss whatever results in a steam power plant by heat transfer from the products of combustion in the furnace to the water in the boiler to evaporate it into steam. The second law analysis shows this to be the largest single item of loss in the whole power plant. The subject of heat transfer is thus an important matter of research for improving the production of mechanical power from heat.

Research in utilizing mechanical power is required in order to minimize the expenditure of fuel for the accomplishment of a desired result. While there are a multiplicity of ways of using power, the main item of such research should be friction, for nearly all the energy of mechanical power is finally dissipated as heat in overcoming frictional resistances. This may appear to be a startling statement; yet if you will think of the movement of a railroad train from Lincoln to Chicago through the burning of say thirty tons of coal under the locomotive boiler, you will appreciate that the tractive effort of the locomotive is expended entirely in overcoming the frictional resistances encountered by the train against the air and rails and in the bearings. In industrial processes in general, a negligible amount of mechanical power is stored up in some form of available energy; nearly all of it is dissipated in overcoming friction. Research upon the frictional resistance of fluids flowing through pipes, of bodies moving through fluids and of the lubrication of bearings is thus of the greatest importance in prolonging the life of our fuel resources.

Economic conditions are bringing about improvements in the production and utilization of mechanical power. For example, the coal consumption per kilowatt hour produced by electric utilities dropped 25 per cent. in the five years from 1918 to 1923. Also, steam locomotives have been developed which, in comparison with the standard locomotives of but three years ago, will haul 50 per cent. more tonnage for the same amount of coal burned. Until to-day, coal economy has been of very minor importance in railroad operation; but conditions are changing, and scientific analysis is now being applied to the steam locomotive with very large improvements in efficiency.

Many other instances could be cited of remarkable developments in industrial processes, if the time permitted.

In the early ages of civilization, slavery was probably essential to progress because only through the enforced labor of the many could the few find time to think. The first use of mechanical power freed the slaves of the Roman Empire from their most arduous labor; but its service to mankind was very slight up to the beginning of the eighteenth century, when a skilled workman could earn in a week only the equivalent of two to three bushels of wheat. Mechanical power then relieved animal power in pumping water from mines and brought coal in large quantities to the service of mankind.

The great inventions in spinning and weaving in the latter part of the eighteenth century, and the application to other purposes of the same fundamental principle, namely, that of transferring the workman's skill and intelligence to machinery, multiplied the uses of mechanical power; but the development was comparatively slow up to about 1870. Just before this date, many of the state universities and endowed technical schools had been founded. The supply of scientifically trained men graduated therefrom resulted in an accelerated development of the production of mechanical power and its utilization by machinery for almost every purpose, thereby causing such widely diffused material prosperity that the skilled worker's weekly wages are now equivalent to twenty to thirty bushels of wheat.

In the fifty years from 1869 to 1919, the population of the United States increased 2.76 times. In spite of the shift in population from the country to the city, so that only one quarter of those in gainful occupations were employed in agriculture in 1919, while nearly one half were so engaged in 1869, the agricultural production increased 4.94 times, or 80 per cent. more rapidly than the population. During the same fifty years, the products of mines increased 18.81 times or nearly seven times more rapidly than the population. The manufactured products increased 9.61 times, or about 3.5 times more rapidly than the population. While many factors contributed to these increased outputs, the most important factor is undoubtedly the increased production and utilization of mechanical power by machinery.

To-day, the drudgery of the struggle for existence has largely been transferred to machinery vitalized by mechanical power, thus making universal education possible by sparing youth from the farm and the factory. May we be able to maintain and even improve our material prosperity by developing more economical methods of producing and utilizing mechanical power—for our necessities of existence must be met before we can find leisure for intellectual development.

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ON THE BASIS FOR THE PHYSIOLOGICAL ACTIVITY OF CERTAIN ONIUM COMPOUNDS[1]

I. INTRODUCTORY PAPER[2]

THE problem of determining the basis for the physiological activity of any substance presents almost insuperable difficulties in the present state of our knowledge of the physics and chemistry of the living cell. In fact, there are those who feel that the problem is not solvable at all, until definite knowledge of living processes is available.

While it is true that a very great amount of work has been done in attempts to determine relationships existing between physiological activity and chemical structure and a number of interesting generalizations within restricted fields have been made, still from all this work substantially nothing has come to light concerning the actual mechanism of the action of any particular substance in the cell. The same may be said of the results that have been obtained in attempting to correlate physiological activity with physical properties.

The difficulties involved are many sided. Some of the first obstacles encountered have to do with limitations of theory and methods of fundamental sciences. The methods of determining, particularly in a biological environment, the various physical effects, as osmotic pressure, distribution, adsorption, interfacial tension, electrical, etc., are deplorably inadequate.[3]

Much, in fact most, of the work done in attempts to deduce correlations with physiological activity has been carried on with substances of rather intricate structures by changing groups involving only a small fraction of the mass of the complex molecule. The effect of this alteration of "side chains" on stability, tautomerism, physical properties, etc., might have been either overlooked or difficult to evaluate. Then, too,

[1] This problem is being carried on in cooperation with Dr. Reid Hunt, of the Harvard Medical School. The physiological data is the basis of another series of papers published elsewhere by him.

[2] Adapted from a lecture given before the New York Section of the American Chemical Society, June 6, 1924.

[3] One can hardly refrain from expressing regret that so few of the better minds in physical chemistry and physics have become interested in the biological applications of their fields.