the species of fish known to have fallen with rains in India. The kinds of fishes that rained in Muzaffarpore in July and August last will be exhibited and attention will be directed to their mode of life, etc.

Five explanations of the rains of fishes have been advanced, namely, (i) hatching out of eggs after heavy rainfall; (ii) fishes wrongly supposed to have fallen with rain might have been migrating overland from one stream or pond to another; (iii) fishes might have been left behind by overflows after heavy floods; (iv) fishes may have been æstivating and have been awakened by the coming of the rain; and lastly (v) the rains of fishes are due to the action of heavy winds, whirlwinds, and waterspouts. All these explanations are discussed by the author and it is indicated that the only explanation tenable is that of whirlwinds and waterspouts. The popular belief of the people of northern Behar regarding waterspouts is given, and in his note Dr. S. N. Sen, Meteorologist at the Alipore Observatory, has shown how waterspouts may be formed in India and by analyzing the meteorological conditions on the two days of occurrence of the rains of fishes in the Muzaffarpore District has shown that during those days the weather conditions were most favourable for the formations of waterspouts over that area. Several other meteorological problems regarding the falls of fishes in India are also discussed.

The Theory and Practice of Drying.

UNDER the joint auspices of the South Indian Science Association, Bangalore, the Society of Biological Chemists, India and the Indian Chemical Society (Madras Branch), an interesting discussion on the "Theory and Practice of Drying" was held on Sunday, the 12th November 1933, in the Central College Chemistry Lecture Theatre, Professor H. E. Watson of the Indian Institute of Science, presiding.

In the course of his opening remarks, Dr. Watson drew attention to the great importance of drying in science and industry. In a tropical country such as India where plenty of sunshine was available, and industries were not highly developed, the problem had not received as much attention as it had in those places less favourably situated, since sun-drying sufficed for many purposes. This simple process, however, was apt to become impracticable when large quantities of material had to be handled and in many cases contamination by dust would render a product unmarketable. It was essential therefore to pay attention to more complicated methods.

Although the theory of drying was similar for all materials, in practice there were wide differences in the methods of treatment. In the first place the temperature to which the material might be subjected was of importance. At one end of the scale were found substances which might be raised to a red heat without deterioration and at the other those which had to be dried at a temperature not exceeding that of the body. A second consideration was the physical nature of the material. With goods such as textiles, the rate of drying depended almost entirely upon the quantity of hot air or other drying agent which could be supplied, while with clays diffusion in the material itself was the controlling factor. In addition to these general considerations a special technique was required in many cases and thus it was evident that the problem was one of great complexity.

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THEORY OF DRYING—I. *M. A. Govinda Rao.*—When solids of appreciable thickness are dried, the moisture must, by some mechanism or other, travel from the interior out to the surface before it can escape into the surrounding drying medium. This mechanism determines the particular variables which govern the rate of drying and the quality of the product.

Materials of fibrous or colloidal nature when brought into contact with air of definite temperature and humidity, will dry up only to a limiting moisture content, known as the "equilibrium moisture content" or 'regain'. It is just the moisture content in excess of this value that is capable of being removed by drying.

If we start with a wet solid, under steady drying conditions, the rate of drying at first remains constant and then falls off. The rate at which moisture can evaporate from a continuous film of water on the solid surface, determines the constant rate of drying, and to a certain extent also the rate during the initial stages of the falling-rate period, until the surface of the solid reaches the equilibrium moisture content. Thereafter the velocity with which water can diffuse outwards from the interior of the solid, determines the drying; the rate of diffusion, and hence of drying, falls off with decreasing average moisture content, or in other words, with decreasing average concentration difference through the solid. During this diffusional stage in drying, neither decreasing the humidity of the drying medium, nor increasing its velocity, will speed up the drying process. T. K. Sherwood (*Trans. Amer. Inst. Chem. Eng.*, **27**, 90, 1931) and A. B. Newman (*Ibid.*, **27**, 203, 310, 1931) have developed equations for calculating the rates of drying for different solid shapes and have represented them in the form of simple curves.

When a wet solid is drying at constant rate, moisture gradients are set up in the interior of the solid. The magnitude of these gradients is of immense importance in the drying of materials which tend to warp or crack. A differential moisture content in the body of the solid causes a differential shrinkage, which must be prevented from becoming dangerously large. E. R. Gilliland

and T. K. Sherwood (*Ind. Eng. Chem.*, **25**, 1134, 1933) have very recently developed equations from which the true moisture distribution inside a slab can be computed at different intervals of drying at a constant rate.

Although all the equations that have been derived are in fairly close agreement with experimental data, the actual mechanism by which the water travels up to the surface is not still properly understood. In several cases the water may evaporate before it reaches the surface; how this factor influences the moisture distribution is a problem requiring further elucidation.

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THEORY OF DRYING—II. *K. R. Krishnaswami.*—Careful control is essential in the drying of crystalline materials with a view to prevent loss of water of crystallisation. Drying in absence of air with the aid of superheated steam, is a process of great utility in dealing with certain classes of substances.

The period necessary for the operation of drying depends upon the area of surface exposed and wherever possible, attempts are made to reduce the material to a fine state of subdivision; where however such reduction in size is not permissible, the drying would be an extremely slow process. Attempts to speed up the process will only result in unequal drying which leads to the production of unsuitable articles; such instances are to be particularly found in the glass and ceramic industries.

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INDUSTRIAL DRYING EQUIPMENT—I. *S. K. Kulkarni Jatkar.*—Sticky and plastic substances, pastes and precipitates are dried in compartment driers provided with devices for circulating hot air over and between the trays containing the material. Substances which are sensitive to heat are treated in a vacuum compartment drier, the material being spread in thin layers on the heated shelves. Tunnel driers are employed when large quantities of materials have to be dried, the material being conveyed on cars continuously with counter current circulation of hot air.

Granular and crystalline materials are dried in rotary driers. The material is fed at the high end of a cylindrical shell directly or indirectly heated with its axis set at an angle to the horizontal and mounted on rollers. The rotation of the drier and the internal flights advance the material to the lower end in showers which meet the counter-current hot air. Sticky materials are handled in mechanically agitated driers of either atmospheric or vacuum type.

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INDUSTRIAL DRYING EQUIPMENT—II. *L. Gopala Rao.*—The simplest form of dryer, whose field of application is however limited, consists of a series of travelling endless belts, on to which the material is suitably fed and dried by passing dry, hot air in counter-current. The use of this dryer for drying chilled soap direct from the kettle has resulted in eliminating the tedious intermediate operations of cooling in moulds, slabbing, cutting and chipping and, particularly, reduced the time from several days to fifteen minutes. Where the material is sensitive to heat, the dryer is enclosed in a special vacuum chamber and the bands slide over steam or water-heated plates which supply the necessary heat.

A common device applicable to various products is the drum dryer. A slowly revolving steam-heated drum dips into a shallow pan or tray (or meets a uniform spray of material) and the resulting thin film is evaporated to dryness in about three-quarters of a revolution and loosened from the drum by adjustable scrapers. Elaborate precautions have to be taken to ensure that a satisfactory film is formed and the scrapers bear on the drum with proper pressure and at an optimum angle. The condensate and non-condensible gases must be removed from the interior of the drum with great promptness, as it is known that the presence of 0.5% of non-condensible gases reduces the coefficient of heat transfer by 50%. For dealing with sensitive materials like milk a vacuum drum dryer has been popular, particularly in America. Apart from the enormous expense and the trouble in discharging the solid product against the vacuum in the dryer, the product is, as a rule, unsatisfactory. Thus it is impossible to produce a reversible milk powder because of the over-heating of the film in contact with the steam heated surface. Steam at sub-atmospheric pressure is sometimes employed for heating, but the consequent low temperature gradient results in incomplete desiccation, and the keeping qualities of the powder are thereby impaired.

The most attractive proposition for sensitive organic substances is spray drying which, although comparatively recent, has displaced the vacuum drum dryer for many purposes. The range of application is unusually wide insomuch as, besides a variety of fluid and semi-fluid inorganic, organic and biological substances, solid precipitates in suspension, such as dye-stuffs, can be satisfactorily handled and a dry powder of uniform particle size produced thereby eliminating the subsequent operations of grinding and sieving. A spray of the material is brought into contact with dry, hot air and as a result of the enormous surface exposed (about 10,000 sq. ft. per gallon), drying is almost instantaneous and the product is collected in bag filters. The adiabatic cooling of the air ensures a very low temperature (about 40°C.) of the particles being dried. Although the average temperature of the drying chamber is appreciably higher, the product is subjected to this temperature only when it is dry and comparatively stable towards heat. Thus egg albumen which coagulates at 60°C. can be spray-dried to a reversible powder with hot air at 100°C. or more. In fact recent practice tends to employ gases at 400-500°C. when dealing with sensitive organic substances.

Hitherto spray drying was considered suitable only for expensive products; but in view of recent developments in industrial process equipment, it would appear practicable to adapt the process to cheaper substances like sugar, and an attempt in this direction is being made by the author. Complicated rotary spraying devices, consisting of discs of special design rotating at ten to twenty thousand revolutions per minute, can be substituted in many cases by cheap modern spray nozzles. Revolutionary designs of dual dust-collecting-and-exhausting fans are available, which would make it feasible to eliminate the customary bulky and expensive bag filters. The drawback of a low thermal efficiency, which is the principal objection against spray drying, can be readily overcome by using products of gaseous combustion, or even exhaust gases from suction gas engines, in place of drying air. Spray drying would then simplify itself into a cheap, rapid and easily operated process suited to common industrial requirements.

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BIOLOGICAL MATERIALS.—I. *M. Sreenivasaya.*—Most of the biological materials are hydrophillic colloids and contain thermo-labile constituents, often sensitive to changes in hydrogen-ion concentration, contamination with heavy metals like lead and copper and atmospheric oxygen. Enzymes, vitamin concentrates, harmones, antitoxins and therapeutic sera, large quantities of which are now being prepared, come under this category. They are usually associated with other relatively inert bodies which have the characteristics of a true colloid.

These products require to be desiccated under conditions least harmful to the essential constituent or the active principle and the operation should be speeded up since the materials are liable to microbial infection in the wet condition. The colloidality renders the diffusion of water through the gel to the evaporating surface slow and the crust formation hinders further evaporation.

In the preparation of most enzyme preparations, treatment with absolute acetone offers a very convenient and rapid method. For example, yeast zymase or Taka-diastase fungus powder is prepared in this manner. When all the constituents are desired the solvent method is unsuitable; film or spray drying is then usually employed.

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BIOLOGICAL MATERIALS.—II. *Gilbert J. Fowler.*—The drying of *Activated Sludge* involves a number of special considerations. Well "conditioned" activated sludge consists mainly of zoogloeal masses of bacteria and other micro-organisms. In bulk it is a gelatinous mass which holds a critical percentage of water very tenaciously. Percentages above 80 per cent. or so can be readily drained off, the remainder constitutes the problem. Left to air dry at temperatures below say 70°F., the drained sludge remains more or less indefinitely as a putty-like mass, if indeed it does not decompose and become offensive.

If dried in thick layers at tropical sun temperature, it is converted into horny lumps difficult to powder.

The method adopted at Milwaukee, where large-scale drying has been undertaken is to drain off the "excess" water on Oilver Filters, and dry the residue with its 80 per cent. moisture at a high temperature in rotary driers. By such a method there is likelihood of loss of nitrogen through driving off of volatile products, and of rendering the remaining percentage less "available" for plant food than is the undried product. Moreover the whole of the 80 per cent. moisture has to be evaporated.

The Fowler Drying Mat, specially devised for the drying of activated sludge, and for which a Patent has been granted in the U.S.A., seeks to avoid these disadvantages.

By employing a surface of stiff parallel vertical fibres on which the colloidal jelly rests (an endless moving band of specially compact coir mat, in fact), the excess water is rapidly drawn away from the film of jelly. When hot air is passed over this thickened jelly as it rests on the mat, the jelly "cracks", and the "bound" water is released and runs away between the fibres of the mat, leaving a thin dry sheet of sludge on the mat, which can easily be brushed off as the mat rotates, and the fibres open at the turn of the mat.

Successful preliminary trials have been made at Cawnpore and Nagpur, and a model is now under observation at the Ishapore Rifle Factory near Calcutta.

The Cawnpore experiments showed that with a film of sludge not exceeding 1/8 inch in thickness, and hot air at a temperature approaching 200°C., the jelly could be dried in about a quarter of an hour.

An air temperature of 200°C. does not mean that the mat reaches that temperature. It is constantly moist with the water percolating from the "cracking" jelly, and the brown paper like film of sludge prevents rapid conduction of heat. It has been found advisable to oil the fibres of the mat in order to prevent adherence of the sludge and penetration of soluble salts into the fibres.

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DRYING OF FOODS AND CONDIMENTS.—*B. N. Banerjee.*—The water content of any food material determines its perishability or keeping quality: cereals, grams and pulses and nuts are non-perishable; less juicy fruits and vegetables like potatoes, carrots, apples and pears are semi-perishable; and juicy fruits and vegetables and other products like milk or eggs are perishable. The practice of dehydration is to prevent perishability and help in the storage of foods and condiments. Dewatering is carried to an extent and in a way, so that the taste, flavour and nutritional value are not lost or impaired and keeping quality ensured. The dried product weighs only a fraction of the original weight and a great saving is assured in packing, labour and transport. The entire product is easily rendered edible on re-hydration.

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SUGAR INDUSTRY.—*G. Gundu Rao.*—Drying in sugar industry which forms generally the very last stage is usually accompanied in the centrifugals where large volumes of air incidentally drawn effect a partial desiccation of the sugar crystals. This process is aided by raising the temperature of the baskets by means of steam.

To secure a more complete drying, the product is carried to an upper floor of the factory and fed into the hopper of a long inclined drum rotating on its longitudinal axis, once in about six minutes. In the interior of the drum and attached to its wall are vanes whose free edges are cut into teeth like those of a saw. A counter-current of hot air (180°F.) blown from the opposite end effects the drying of sugar in about 20 minutes. There are several modifications of such driers. Recently, the Jenkin's vertical type of drier is coming into favour. The chief feature of this type is a central rotating shaft carrying trays along its length. Sugar is fed into the topmost tray and is then thrown down from tray to tray as the shaft rotates. The sugar crystals have a chance of being exposed to the upward stream of hot air for the maximum length of time and the possibility of incrustation is thereby reduced.

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DRYING IN PAINTS AND PIGMENTS. *S. K. Datar.*—Pigments required for paint manufacture are either obtained from natural sources or prepared by precipitation. Natural pigments require powdering or levigating or both before they can be utilised. There are machines to powder coarse pigments dry in one operation to 300-400 mesh; in other cases the pigments are levigated in water. Both levigated and the artificially precipitated pigments which have a varying water content of 20-50 per cent. require to be thoroughly dried before they can be incorporated in the paints.

Their water content can be reduced to a certain extent by filter pressing at high pressures, but for preparing them in a dry condition they require further treatment. A simple way of drying is to leave the pigment in trays in thin layers on racks for days, exposed to air, but this or even the sun drying are slow processes and are subjected to contamination by gritty particles and dust. A quicker way is to dry in suitably constructed chambers heated by fire, steam or electricity. In the case of white lead simple open air drying is extremely slow and involves the risk of contamination by dust and discolouration. Drying in a chamber heated by flue gases has been found to be uneconomical.

By replacing water in filter-pressed white lead with linseed oil, the process of drying can be completely eliminated. The old way of preparing the paint was to mix previously dried and powdered white lead with oil in a pugmill. The modified process, in which the white lead from the filter press containing about 25 per cent. water, is directly pugged with linseed oil, has proved successful as the white lead has an affinity for oil in preference to water which readily separates.

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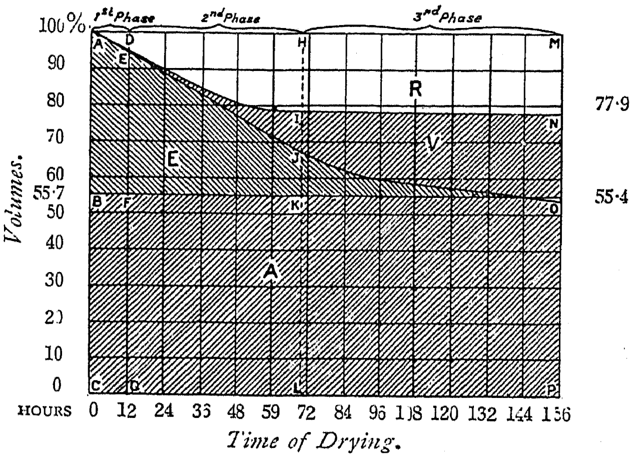
CERAMICS.—*N. V. Raghunath.*—Wet process, Dry process and Casting process are three methods of manufacture of porcelain.

The prepared body material employed in the wet process contains 25 per cent. of moisture. As soon as the articles are shaped in Plaster-of-Paris moulds constituting the moulding material to absorb water thus leading to a shrinkage in volume of the article. The greatest care has to be taken to see that the articles do not crack while in the moulds. A high humidity of the surrounding atmosphere ensures favourable conditions for drying and prevents "case hardening".

In the first stage (see figure) the shrinkage is proportional to the amount of moisture driven out. In the second, shrinkage and pores occur as well as the driving out of a certain amount of moisture. In the third stage, there is no shrinkage but only loss of water and the formation of more pores.

The chemically combined water is driven out at a higher temperature and at 500°C. it is completely driven out. The chemically combined water



Drying Chart.

R.=Shrinkage. E.=Water. V.=Pores. A.=Clay.

is driven out in kilns which are fired by coal, gas, electricity or wood.

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DRYING OF TIMBER.—*C. Varadhan.*—The chief objects of drying timber are to reduce its weight, to increase its strength, to prevent decay and to minimise changes in its dimensions, after it is made up into furniture, etc. The moisture in wood is of two kinds, free moisture contained in the cells and hygroscopic moisture absorbed by the cell walls. The problem in all processes of drying timber is to remove all the free water, without producing case-hardening, unequal shrinkages and other defects which ultimately result in cracking and splitting of the wood. Modern methods of kiln-drying in which the wood is stacked in kilns, consist of drying by properly conditioned air. The heating is done by steam pipes, the humidity controlled by steam or water sprays and the circulation effected by convection currents or forced draught. The actual temperature, humidity and other working conditions depend on the particular species of wood. Among other methods of seasoning are the old haphazard one of seasoning in the open air, soaking in water followed by air-drying and the electrical methods.

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Messrs. B. Sanjiva Rao and K. L. Ramaswami in presenting laboratory aspects of drying, dealt with the relative efficiency of several desiccating agents. Mr. Krishna drew attention to the importance of drying in the pharmaceutical industries where preservation of the potency of drugs like digitalis is greatly influenced by variations in moisture content.

A detailed discussion followed under various aspects of the problem.