

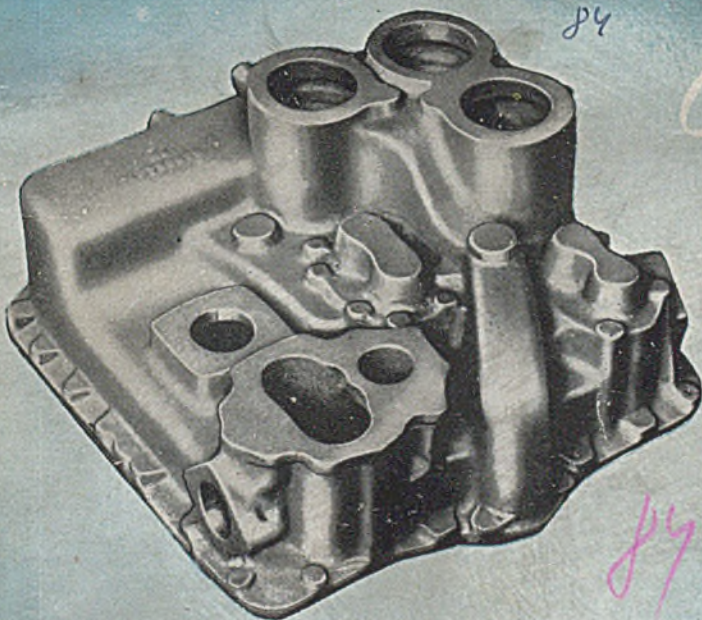
SUPPORTING OVERHEAD TRANSMISSION LINES

# LIGHT METALS

JANUARY  
1945

16

STERLING METALS LTD.



*Coventry*



SABRE Engine Oil Sump  
in ELEKTRON Magnesium  
Alloy.

SAND & DIE CASTINGS IN

**ELEKTRON** AND **ALUMINIUM**  
MAGNESIUM ALLOYS      NORMAL & HEAT TREATED

'ELEKTRON' FORGINGS

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REFINED ALUMINIUM ALLOY INGOT  
IS OUR ONE JOB  
AND WE DO IT  
AT THE HIGHEST LEVEL OF EXCELLENCE  
KNOWN TO SCIENCE



LIGHT ALLOY PRODUCTS CO. LTD., MINWORTH, BIRMINGHAM.

P.109/45

**'WHY PICK ON ME?'**



Because you're the boy we're working for to-day, bless your good heart. You've got things more urgent than pressure die-castings to think about. Perhaps you've never heard of them. But you're certainly using them. There's hardly one single bit of equipment, hardly a weapon, certainly not one single vehicle in the Army that doesn't include die-castings.

Pressure die-casting helped us to turn out that stuff quickly when you badly needed it. It helped us to turn it out in the vast quantities

**B.D.C.**

that our growing armies called for. May your equipment serve you well.

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*To-day all our time and skill is given to the equipping of our fighting men. We'll gladly talk of how we can serve your post-war needs; but please don't ask us to do much about it just yet!*



At the moment only half the story can be told. Not until the peace has been won can we tell you of the war developments which will be incorporated in the post-war design and manufacture of our Optical-Mechanical-Electrical Instruments and Aircraft Equipment.

AVIMO LTD., TAUNTON  
Somerset (England)

Approved under Air Navigation Rules  
for Civil Aviation.



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of Aluminium and its Alloys

## CHROMATING

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## TECHNICAL PLATINGS LTD.

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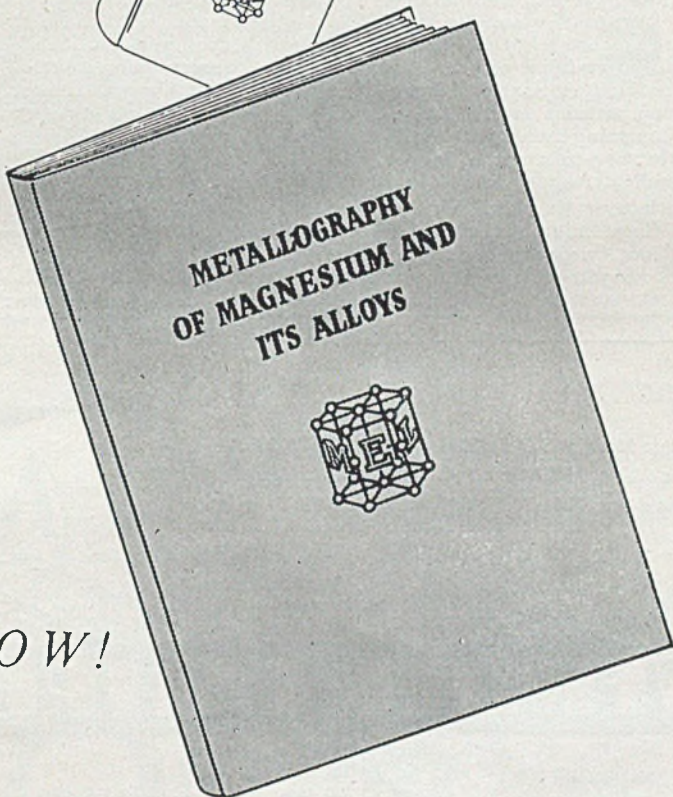
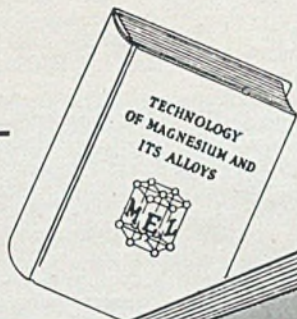
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Phone: PAD. 1486. (p.a.x.)

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*the pioneer*  
**MAGNESIUM ALLOYS**

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PLUS 6d POSTAGE IN U.K.  
CHEQUES TO BE MADE OUT  
TO F A HUGHES & CO. LTD.

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## The Importance of Choosing the **RIGHT** Supplier of Non-Ferrous Castings . . . . .



In planning products incorporating castings in non-ferrous metals the most momentous question with which you're faced is your choice of supplier. Fortunately, you'll find more than one who can meet every requirement. But remember your casting supplier bears the entire responsibility for the production of a vital part of your product.. for solving engineering problems.. making patterns and dies...casting the job.. finishing each piece.. and feeding it into your production lines as your schedule demands.

Here at Universal, with one of the finest equipped plants in the Midlands, we offer a complete service..designing, engineering, pattern and die-making, casting, finishing.

All are handled within our own organisation and co-ordinated under a single engineering and operating group.

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GRAVITY DIE CASTINGS, PRESSURE DIE CASTINGS  
AND SAND CASTINGS IN NON FERROUS METALS

CASTLE BOULEVARD · NOTTINGHAM

and at CALLARD HOUSE, REGENT STREET, LONDON, W. 1

English : Nos. 206S 6" ; \*206 6" ; 209 9" ; 212 12".

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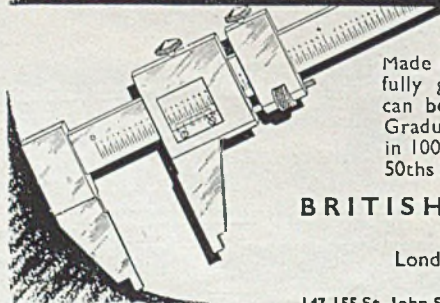
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Made to highest possible standards of accuracy and fully guaranteed. Hardened and ground jaws ; can be used for inside and outside measurements. Graduated in 40ths of an inch, with vernier readings in 1000ths, or in  $\frac{1}{2}$  mm., with vernier readings in 50ths of mm. Packed in plush-lined mahogany case.

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London Office : 25, Manchester Sq., W.1

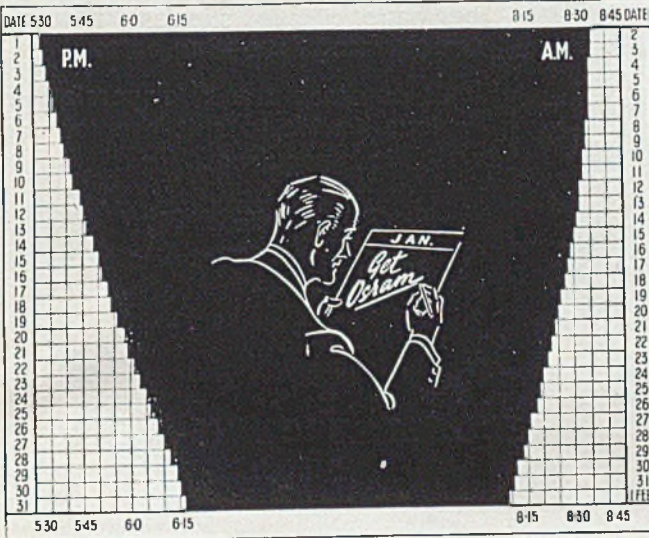
Agents : Stedall Machine Tool Co.,

147-155 St. John St., London, E.C.1. Phone: Clerkenwell 1010 (10 lines)



# New Year Resolution

## BLACK-OUT CHART FOR JANUARY



Reproduced from the Nautical Almanac by permission of the Controller of H.M. Stationery Office

### MOON PHASES



\*Times shown are those for the London area.

You will strive more than ever to keep the wheels of output running smoothly and ever faster.

You will see that working conditions lack nothing that will contribute to the comfort and well-being of the workers.

Special care will you take with lighting—that essential and beneficial factor in every industrial plan.

To make sure of reliable lighting service, you will resolve to make 1945 another OSRAM year.

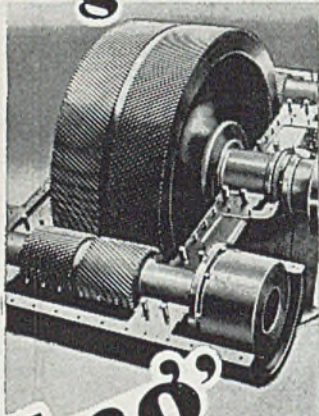
# Osram



## THE WONDERFUL LAMP

Advt. of The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

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"Dag" colloidal graphite gives a permanent thin slippery film to the surface of working parts.

It is obtainable as a dispersion in various liquids to suit the job for which it is required.

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**'dag'**  
REG. TRADE MARK

*colloidal graphite*  
**REDUCES MACHINE-WEAR**

*Workers love it — Directors praise it*



**It has  
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Always provided it is the right kind of music and can be heard clearly in spite of factory noises. Otherwise more harm than good may result.

Subscribers to the T.R. Music Service are enthusiastic regarding the benefits it brings. For T.R. have a wide range of equipment which is

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Relieves fatigue, increases con-  
tentment, helps maintain output

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Synchronised Time uniform to  
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# PLUSTICITY

"BIRMABRIGHT" implies plasticity . . . "plus": plasticity being an outstanding characteristic of the B.B.3 and B.B.5 alloys, which can be manipulated with ease and with confidence. The "plus" characteristics are . . . +1 . . . deep drawability—comparable with steel sheet . . . +2 . . . normal forming with steel sheet annealing . . . +3 . . . full mechanical properties attained without heat-treatment . . . +4 . . . absence of age-hardening effects . . . +5 . . . welding quality available in B.B.3 . . . +6 . . . easy machining coupled with high polish . . . +7 . . . high standard of corrosion resistance . . . +8 . . . excellent response to anodic treatment . . . +9 . . . B.B. alloys available in all forms.

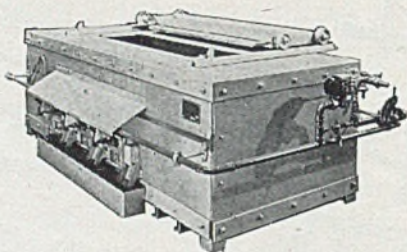
So "BIRMABRIGHT" has something . . . Plasticity plus nine other desirable qualities. One word describes its virtues . . . "PLUSTICITY." In case you do not know, "BIRMABRIGHT" is the registered trade mark of the well-known aluminium-magnesium-manganese alloys manufactured by . . .

BIRMETALS LIMITED  
QUINTON BIRMINGHAM.



# What can *YOU* do about fuel cuts?

All inefficient furnaces should be replaced at the first opportunity with modern Brayshaw furnaces having adequate heat insulation, advanced methods of control, etc.



## ***RESULT***

Part, or all of the fuel cuts obtained without curtailment of production, a higher standard of heat treatment, and improved shop conditions.

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## **MEERLOO**

*True Cut*

SPECIALLY HARDENED

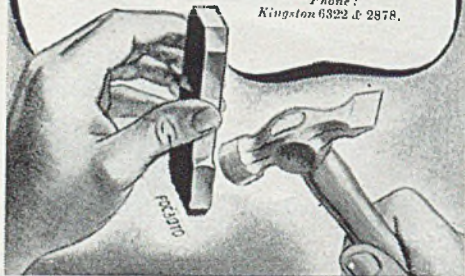
## **STEEL STAMPS**

*On Air Ministry Approved List No. B/41693/39*

Large Output. Prompt Deliveries.

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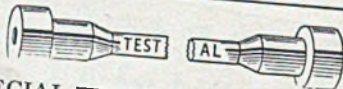
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Phone: ALINGOTS, BIRMINGHAM  
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### **ALUMINIUM INGOTS**

WROUGHT AND CAST ALLOYS IN ACCORDANCE WITH AIR MINISTRY AND ADMIRALTY SPECIFICATIONS UNDER OUR OWN LABORATORY CONTROL



### **SPECIAL BRAND TESTAL 424**

The specification is in accordance with D.T.D. 424. The Brand TESTAL vouches for "HIGH GRADE" degassed and grain refined material

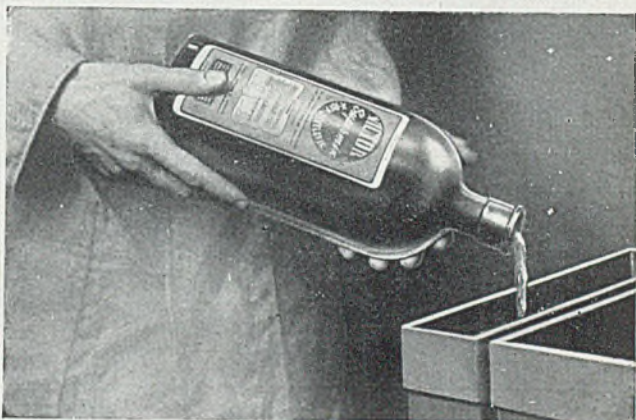
D.T.D. 424 where required is also supplied SODIUM MODIFIED or with the addition of TITANIUM

**NEW!**

**VICTOR** *Supermix*

LIQUID

**X-RAY FILM PROCESSING CHEMICALS**



**SUPERMIX PRICES**

Developer :

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|-----------------|------|
| to make 1 gall. | 6/6  |
| " " 2 "         | 11/- |
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Fixer :

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|-----------------|------|
| to make 1 gall. | 5/6  |
| " " 2 "         | 9/-  |
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*.... it's as easy as that -*

You simply pour these liquid concentrates into your tanks and add water . . . . . no time lost in dissolving powders or adjusting solution temperatures. They will reveal in every film all the diagnostic qualities which your exposure makes possible, in contrast, density and detail.

*.... and as economical as this -*

With these longer-lasting Supermix solutions you can process up to 75% more films than with conventional processing chemicals. Unusual speed of developing (3 minutes at 68° F.) and fixing (less than 1 minute) will expedite your darkroom work ; or, by developing 5 to 6 minutes you can reduce x-ray exposure 20% to 25% to economise in tube life. LONG-LIFE . . . . . SPEED . . . . . CONVENIENCE . . . . . are the hall-marks of Victor SUPERMIX.



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# STEIN

## Refractories

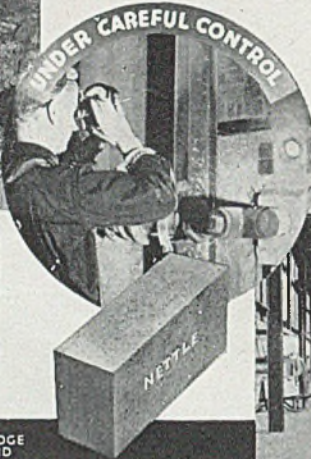
### CREOSOTE-PITCH FIRING

A number of firms adopting this fuel have encountered new Refractory Problems caused by corrosion and Vitrification Spalling.



*Made from*

**SELECTED RAW MATERIALS**



UNDER CAREFUL CONTROL

**IN A MODERN PLANT**



If a suitable design of burner is used, the trouble can usually be overcome by using a High Alumina Firebrick such as NETTLE (42/44% Alumina)—a point proved by the practical experience of several customers. An additional protection to the brickwork by washcoating with Maksiccar II. or Stein Sillimanite Cement will often be found economic. Further information will be gladly supplied on request.

**JOHN G. STEIN & CO LTD** BONNYBRIDGE SCOTLAND

**URGENT**

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**HANDLED IMMEDIATELY**

We are specially equipped with large up-to-date plant, for anodising Aluminium and its alloys in NATURAL OR COLOURED FINISHES; Chromating of Magnesium; Zinc; Cadmium; El-Tin and Silver Plating and other processes. A.I.D. approved.

**TELEPHONE**

**Radcliffe**  
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HOLLAND STREET RADCLIFFE LANC.

Is it

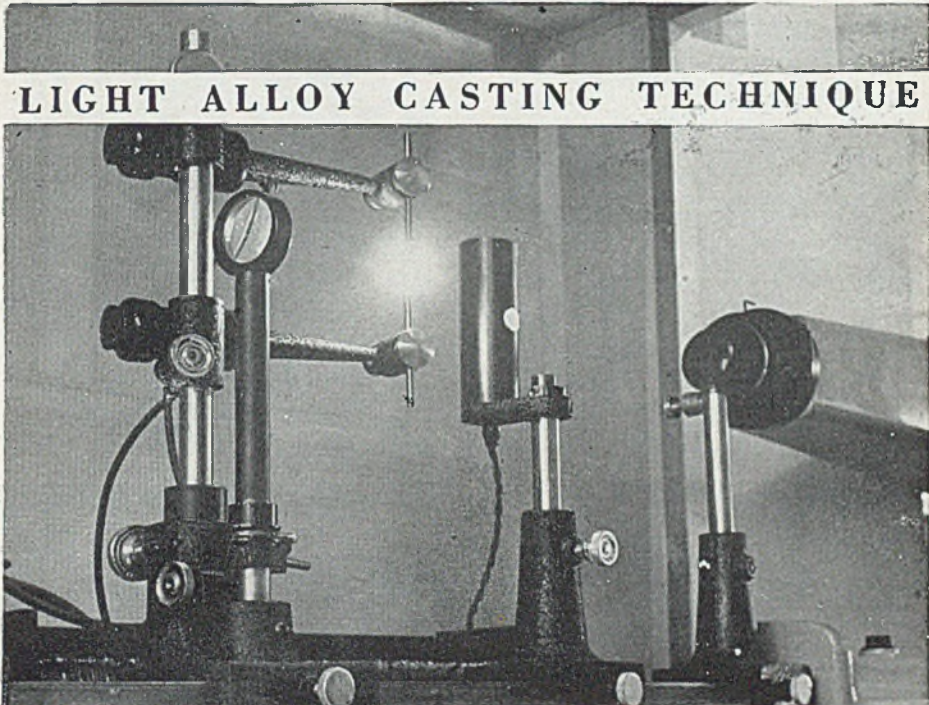
# Die Castings

you want?

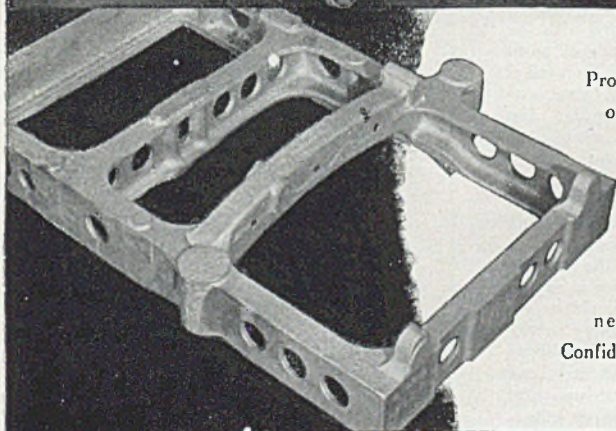
in BRASS, ALUMINIUM or ALUMINIUM-BRONZE

- Owing to the restricted use of Aluminium, Dies for producing Aluminium Castings can be modified for Brass Production.
- Let us, as the Pioneers of Brass Gravity Die Casting, help you in your Technical Problems.
- Our Highly Skilled Technical Staff, Modern Foundries and many years' Experience are at Your Service.

**NON-FERROUS DIE CASTING CO. LTD.**  
North Circular Road, Cricklewood,  
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## LIGHT ALLOY CASTING TECHNIQUE

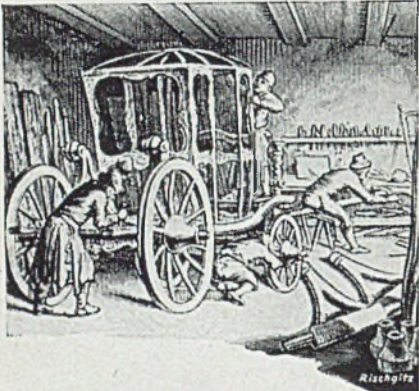


Production at Kent Alloys is founded on a basis of accurate laboratory control at every stage. It is the spectrographic control of alloys, the radiographic control of castings which, combined with certainty as to tensile strengths and hardness, ensure Consistency and Confidence.

*Specialists in  
Light Metal  
Castings*

**KENT ALLOYS LTD.**

**HEAD OFFICES: COMMERCIAL ROAD, STROOD**



# PRODUCTION LINE

## 18<sup>TH</sup> CENTURY

The mid-18th century seems to have been the golden age of the coachbuilding craft in Britain . . . an age which produced the existing state coach of the Lord Mayor of London and the British Royal State Coach. Coaching was then, of course, largely a diversion for gentlefolk. Expense was no object, and every production stage from axle-tree to finishing-varnish was a job for skilled hands. A lengthy process, yes . . . especially when Nature was saddled with the task of drying those endless coats of paint and varnish so flattering to milord's vanity. Today when craftsmanship must give way to mass production, when painting and varnishing have been reduced almost to matters of formula and temperature . . . a modern fuel is playing a big part in countless priority jobs. Gas is not only helping the paint and varnish manufacturer in the mixing and heat-treatment shops and in the boiler room. It is keeping pace with the moving production line in gas-fired conveyor drying ovens for enamel, lacquer and varnish work. It is helping the paint manufacturer in the continuous development of new high-speed infra-red techniques for the drying and curing of a wide variety of new industrial finishes. Thanks to Gas, the modern industrialist can plan production on the basis of a quick, cheap, reliable fuel . . . a fuel which is simple, flexible and accurate in control . . . a clean fuel which can be stored at its source of supply . . . and tapped at its point of use.

## THE TWENTIETH-CENTURY INDUSTRIALIST KNOWS THE VALUE OF GAS

Visit the Kitchen Planning Exhibition, Dorland Hall, Lower Regent Street, London, S.W.1. February 6th to March 3rd. Daily 10 a.m. to 5 p.m. (6 p.m. Thursdays). Admission Free.

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## NON-FERROUS CASTINGS

War-time research opens a wider field for British Engineering into new and essential uses of non-ferrous metals and alloys. Our specialised knowledge is offered to you in castings of

**PHOSPHOR BRONZE, GUNMETAL, ALUMINIUM, MANGANESE BRONZE and in ALUMINIUM BRONZE** which possesses a Tensile Strength of 45 tons per square inch.

Also 'BIRSO' Chill Cast Rods and Tubes, Centrifugally Cast Worm-wheel Blanks, Finished Propellers and Precision Machined Parts, Ingot Metals, etc.

Fully approved by Admiralty and A.I.D.

# T.M. BIRKETT & SONS LTD.

## HANLEY · STAFFS

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# FOSECO PREPARATIONS

**COVERALS** For cleaning and covering aluminium and its alloys. Absorb oxide, give metal-free drosses and greater fluidity. Numerous grades are manufactured.

**DEGASERS** Efficiently and simply remove gases and oxides from aluminium and aluminium alloys. Eliminate pinholes and improve physical properties. Efficient grain refining is obtained in conjunction with degassing. Various grades available. Write for full particulars.

Above are only two of many "FOSECO" preparations for producing better castings at lower cost. Foundrymen are invited to write for further particulars to:—

**FOUNDRY SERVICES LTD.**  
285/7, Long Acre, Netchells, Birmingham, 7



# Selfridges

## POST WAR CO-OPERATION

*Extract from Chairman's Statement issued  
with the Company's Annual Report :*

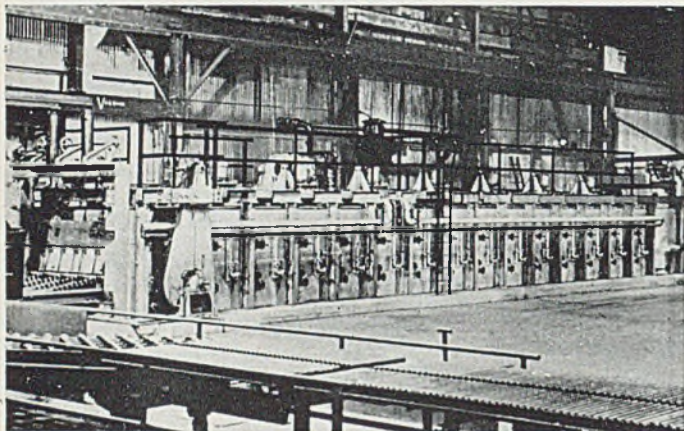
" Those who are planning new ventures will have been  
 " encouraged by the announcements of the leading Banks to  
 " provide finance in a liberal measure for efforts of promise.  
 " Ideas and talents in production combined with finance can go  
 " far, but the third essential is experience of distribution and it  
 " is here I feel the large Stores can help. The extent to which  
 " overseas markets in the past have had to be searched in order  
 " to obtain new lines of merchandise and novelties has not been  
 " fully realised. The urge to ' Buy British ' will be greater than  
 " ever—quite apart from the limitations which are likely to be  
 " placed on the amounts of currency available for imports. This  
 " surely provides a vast field of opportunities for new endeavours  
 " and Selfridges will be anxious to offer services for displays,  
 " publicity and support in connection with any new productions  
 " of promise in wood, plastics, metal, leather, rubber, textiles,  
 " china and glass or other materials, and to render, if possible,  
 " aid in co-operating with the production and marketing of such  
 " merchandise whether by existing Houses, new businesses or  
 " private individuals."

\* \* \*

**SEFRIDGES Limited, Oxford Street, LONDON, W.1**

*Issued by the Merchandise Office.*

## ALUMINIUM & ALLOY RE-HEATING FURNACES



The Furnace illustrated is heated by a series of Gas Fired Radiants. The waste gases from the radiants can be diverted either into the heating chamber in contact with the product, or can be evacuated direct to the chimney. The temperature is controlled by Multi-Zone Automatic Pyrometric Equipment, which together with the Gibbons' System of Heating and Fan Re-circulation ensures close temperature control.

Gibbons Bros. Ltd.,  
Dibdale Works,  
Dudley. Phone 3141

FOR ALUMINIUM AND ALLOY BILLETS OR SLABS

# GIBBONS

RE-HEATING FURNACES

M-W 72

## JABROC

FOR TOOLS, JIGS  
AND TEMPLATES



## INSULJABROC

THE IDEAL MATERIAL  
COMBINING MECHANICAL  
STRENGTH AND HIGH  
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PAPER & FABRIC BASED  
INSULATION MATERIAL  
FOR HOUSEHOLD AND  
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LOW & HIGH VOLTAGE

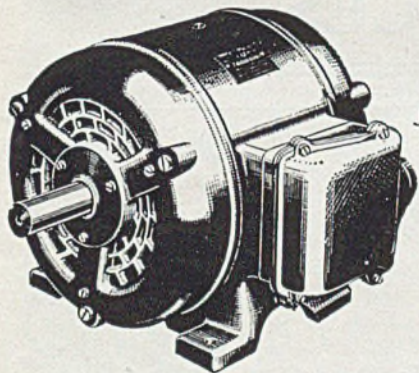
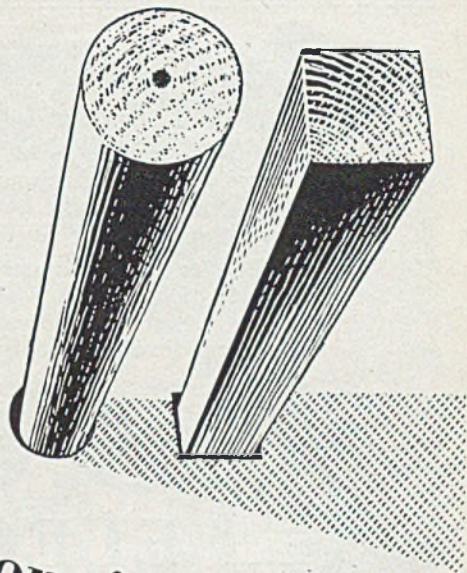


MOULDED COMPONENTS [JABLO] LTD.  
*The Pioneers of Laminated Plastics*

22 OLD QUEEN STREET - LONDON - S.W.1



You will find  
the *right* motor in the  
Parkinson range.



There need be no risk of square peg motors doing round hole jobs if you have the Crompton Parkinson catalogue on your desk. There, in the standard range of over 2,000 types, you will find the correct motor for almost every need.

These motors are made by a flow

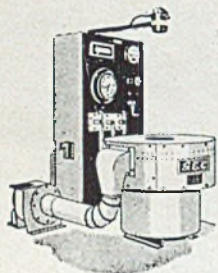
production system in which finished parts and sub-assemblies are standardised and stored, where the complete motor is of a type not stocked. Final assembly is quickly completed. Speed and selection are thus allied with Crompton Parkinson's exacting standards of motor production.

  
**CROMPTON PARKINSON**  
 LIMITED

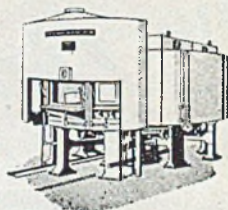
# Metal ON ITS METTLE

Throughout the national effort runs the need for metal—more metal, better metal, tougher metal—strengthened and vitalised by heat treatment.

G.E.C. Electric Furnaces provide an answer to every problem of hardening, tempering, annealing, nitriding, etc., by which the inherent strength and stamina of metal are developed to meet ever more exacting uses.



## G.E.C. ELECTRIC FURNACES



Advt. of The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

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—fat or thin—Shannobic folders take all shapes and sizes of papers or lists, and because they hang on a frame, never slip or hide. Large adjustable angled tabs ensure instant finding. Shannobic fits into any filing system, big or little, or the Desk Top Unit shown is ideal for emergency desk tables. Send 1d. stamp for leaflet describing how Shannobic can serve you.



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IMPERIAL HOUSE, (Dept. E.3), 15-19, KINGSWAY, LONDON, W.C.2

And at Birmingham, Bristol, Liverpool, Manchester, Newcastle, Glasgow (Agent)



## *... as the wave of a hand*

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# LIGHT METALS

*Proprietors:*

TEMPLE PRESS LTD.

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ROLAND E. DANGERFIELD

*Dealing Authoritatively  
with the Production, Uses  
and Potentialities of  
Light Metals and  
their Alloys*

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## EDITORIAL OPINION

### Now Where Do We Go?

FOR the first time since the early days of the war, aluminium and magnesium are once again free for release to manufacturers for civilian production. It is no easy matter to appreciate, at once, what this means, as on no other occasion in our history has such a rigid restriction of raw materials of this nature ever been so long imposed. It should be pointed out that the official note in this regard makes it quite clear that, whilst supplies of light and ultra-light alloys are such as to justify general release, war requirements can still exert an over-riding priority. Furthermore, those contemplating the production of aluminium or magnesium articles for everyday use must have available plant and labour not actually engaged on more vital work.

First and foremost, perhaps, due attention must be given to the widespread demand for aluminium hollow-ware. How seriously the deprivation of our light-metal kitchen utensils has affected us all is only just making itself felt, when, at last, the few pots and pans not handed over in response to Lord Beaverbrook's appeal have begun to show signs of irremediable wear. The aluminium kettle, once so callously left to boil dry, has acquired in our sight a value sufficient to make it quite certain that this form of martyrdom will not be encouraged again for many a long year. These, however, are our immediate needs.

With the gradual transference of further supplies of aluminium, those less personal items to which we had become accustomed to see in aluminium will also be once more available: vacuum-cleaner bodies, light-weight barrows for the amateur gardener, washing-machine boilers and the like. To this point the chain of development is fairly obvious. Far more interesting, however, is the expansion of aluminium and magnesium into those fields where, prior to the war, little had been done to assess their value as practical materials of construction on any large scale, or where, for economic reasons, they could not be widely taken up.

Yet a further point concerns the disposal of the vast quantities of semi-manufactured metal retained by the Government. Some of this, presumably, can be utilized for the purposes we have outlined, but, first and foremost now, whenever we think of materials in sheet form, there comes to mind the housing problem—one of so serious a nature that it demands a priority little less urgent than that of war-like supplies themselves.

Is it out of place tentatively to suggest that some of this redundant sheet might well be used for emergency repairs? It is easily handled, readily fixed down to battens or joists by nails or screws, requires no painting, is not harsh to the eye, and, with very little trouble, can be utilized for roofing, ceilings, wall panels and flashings. No novel or dangerous experiment is being suggested here. In past issues of "Light Metals" many pages have been devoted to the application of aluminium in these connections where it has given good service, in some cases for periods to 50 years or more. With all due deference we most strongly commend to the Ministry of Works and Light Metal Control that they bend their minds to this possibility.

Our purpose in making this suggestion is twofold; first, we have it in mind that light metals can lend a hand in solving a most pressing and dangerous situation. Secondly, and, perhaps, in the long run, more important, is the fact that, utilized in this way, aluminium will be given an opportunity publicly to demonstrate its affinity and oneness with sheet metals at large. For a variety of reasons there has, in the past, been a tendency to segregate it to the ranks of special materials—those needing more than the normal care given to the handling of metal in sheet form; those which can be used for this purpose or cannot be used for that, etc. The time has come when such "class distinction" must be abolished.

In everyday work, considerable importance attaches to the ease with which a material may be manipulated, and here we do not mean under large scale manufacturing or production conditions, but in the hands of the jobber, and the nominally unskilled.

It is still too early to predict the final position which will be taken by light metals in the post-war era, but this much is quite certain: the civilian market, so long starved for supplies, is already eagerly demonstrating its anxiety to make good the deficiency.

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*THE FACT* that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

**SAVE PAPER.**—More than ever is paper waste required for our war industries. Waste paper makes munitions in a hundred forms—from shell cases to aeroplane parts.

# Founding of Magnesium Alloys

*Continued from p. 562 of the November Issue of "Light Metals," this Section of the Account Deals with Fluxes, Fluxing Technique, and Superheating*

THE mere process of melting magnesium alloys is, in itself, not difficult. The usual aluminium-magnesium alloys commence melting at 435 degrees C. and are completely fluid at about 580 degrees C. The pouring-temperature range is between 700 degrees C. and 780 degrees C. and, whilst superheating is employed up to 900 degrees C., it will be seen that there is no really high temperature to be considered. In a word, the temperature range adopted is approximately the same as that used in aluminium founding.

Melting crucibles made of iron or steel are used, for there is practically no iron pick-up in the case of magnesium. It is true that, in the United States of America, alloys of super-purity have been produced recently, for which iron or steel pots could not be used. The iron content of commercial magnesium alloys seldom exceeds 0.030 per cent., but the American workers were aiming at an iron content not more than a few thousandths per cent. It is sufficient to say that even on repeated remelting in a pot of ferrous materials, the iron content of magnesium alloys does not appreciably increase.

The iron or steel pot material must, however, not contain ingredients which themselves dissolve in molten magnesium; for this reason nickel-bearing ferrous metals must be avoided. It is said that nickel can easily contaminate the melt, with adverse effect on the corrosion resistance and mechanical strength of the resultant alloy.

As indicated in the first part of this account, magnesium is quite reactive towards air and moisture. It is well known that the speed of a chemical action increases at an alarming rate as the temperature increases, and if it be true that magnesium reacts with boiling water (which is, in effect, an oxidation reaction at 100 degrees C.), need for a special method of treatment of molten magnesium at, say, 750 degrees C., will cause no surprise. It has also been shown that the surface skin of the molten metal offers no protection whatever.

The use of fluxes, then, is a necessary part of the melting process for magnesium alloys. Fluxes are, in general, used for one of two purposes. Some refine or purify the molten metal, either removing the impurities by chemical combination, or by physical absorption of them. Others, again, are used to provide a cover on the metal surface, thus protecting the alloy from oxidation or absorption of furnace gases. Magnesium melting fluxes are used for the purposes of purification and protection; and although two separate fluxes are often employed, a single, "double-purpose" flux may successfully be used. As will be shown, whether one flux or two be required depends entirely upon the composition of the salt mixture.

To visualize quickly the required fluxing technique: as magnesium melts in the pot it is dusted with a flux of such a melting point that it is fluid just before the metal reaches the completely molten state. The melt, then, is covered ultimately with a liquid seal which effectively prevents oxidation.

It is too much to hope, however, that no oxide will have been formed during melting, and hence included within the metal. The optimum mechanical properties of any metal cannot be attained if discontinuities, whether non-metal or gaseous, be present; it is necessary in this case, therefore, to remove the oxide contamination.

Removal of oxide inclusions is effected by a further fluxing process. A flux, of suitable chemical composition, is now vigorously stirred into the metal (after, of course, allowing the flux to become molten on the surface of the melt). This refining acts primarily by chemical combination with the magnesium oxide, although there is some evidence that it is, in part, due to physical sedimentation of impurities.

From the point of view of oxide removal, anhydrous (i.e., water-free) magnesium chloride is the chief ingredient of magnesium fluxes, and, indeed, the amount of this substance may amount to 80 per cent. of the flux. Perhaps an average proportion is 45 per cent. Anhydrous magnesium chloride, for all its chemical activity as regards magnesium oxide, is never used alone. In the first place, melting as it does at about 800 degrees C., it would offer no protection during melting, and secondly, this temperature is rather high for manipulation of molten magnesium. The agitation due to stirring would lead to further oxide production, which, of course, is the very thing to be avoided.

Foundrymen will know that the melting point of alloys of two metals is, in general, less than that of either of the two constituents; the same observation is true of salt mixtures. Thus suitable additions are made to the anhydrous magnesium chloride in order that a flux of more convenient melting point be secured. In point of fact, another magnesium salt—the fluoride—is most often used as the second constituent present in large proportion, although smaller amounts of such substances as sodium chloride, potassium chloride, calcium chloride and calcium fluoride are added to obtain precisely the correct fluidity and density.

It may be assumed that we now have a flux mixture of low enough melting point to be efficient as a protective cover, and of suitable viscosity at the refining temperature. Refining is carried out at temperatures between 700 degrees C. and 750 degrees C.

During the intimate mixing of flux and metal,

the flux absorbs oxide and so becomes thicker, or more viscous. A portion of the flux will consequently sink to the bottom of the pot, whilst the remainder will rise to the surface, a small amount also adhering to the pot wall. This thickening of the flux during the course of its refining action is most important, for if it did not occur, the fluid flux would remain suspended throughout the volume of metal. Such an ineffective process was probably the reason for the early complaints made against magnesium castings. The presence of chlorides in the solidified metal gives rise to violent destructive corrosion, and lack of perfect separation of flux from metal was undoubtedly the cause of the vicious corrosion associated with early casting production.

The degree of thickening of the flux will depend upon the amount of oxide to be absorbed. It seems that the impurity was depended upon to give separation, and a big step forward was made in magnesium founding when fluxes were elaborated that would not only absorb the oxide, but were, at the same time, sufficiently viscous to be separated without contamination of the metal, even when the oxide content was small. The thickening action is known by the term "inspissation," a word that has become accepted as part of the vocabulary of magnesium technology.

The further value of magnesium fluoride as a flux ingredient is in the fact that it is an inspissating agent, and, by its use, a flux may be prepared that has the right combination of melting point, oxide absorption and viscosity.

A rather imaginative view of fluxing action is held by some French technicians. They maintain that flux acts chiefly by entrainment of foreign particles, followed by precipitation, on the analogy of the action of gelatine or isinglass on cloudy beer and wine which are rendered brilliantly clear as the gelatine slowly deposits itself at the bottom of the vat. There is some evidence that fluxing may, to limited extent, be truthfully described in these terms.

It may be of interest to give a few samples of flux compositions. The first two are taken from Haughton and Prytherch: "Magnesium and its Alloys," H.M.S.O., 1938, whilst the third is taken from British Patent Specification No. 548,381.

(1)

|                                 | Per cent. |
|---------------------------------|-----------|
| Anhydrous Magnesium Chloride .. | 72        |
| Magnesium Fluoride .. .. .      | 28        |

(2)

|                                   | Gms. |
|-----------------------------------|------|
| Calcium Fluoride .. .. .          | 40   |
| Sodium Fluoride .. .. .           | 60   |
| Potassium Chloride .. .. .        | 320  |
| Magnesium Chloride (anhydrous) .. | 900  |

(3)

|                                   | Per cent. |
|-----------------------------------|-----------|
| Magnesium Chloride (anhydrous) .. | 45        |
| Alkali Chloride .. .. .           | 37        |
| Magnesium Fluoride .. .. .        | 18        |

Magnesium is the most chemically active of the commercial structural metals; as indicated in the opening instalment of this account, even salt solutions have appreciable attack. Flux inclusions, consisting of anhydrous magnesium chloride among other salts, are particularly disastrous. The anhydrous salt is attacked by

water with the formation of magnesium oxychloride and hydrochloric acid. In turn, the hydrochloric acid reacts with more magnesium giving magnesium chloride and hydrogen, and so the cycle tends to repeat. Now, correctly manufactured and processed magnesium-alloy castings can be shown to be remarkably useful even in marine conditions, but the presence of a small flux inclusion gives rapid corrosion.

Flux-free castings are produced nowadays as a matter of course. Indeed, if any castings are scrapped on account of flux corrosion, it is due either to the use of unsuitable flux, or to gross carelessness on the part of the furnaceman. Nevertheless, seeing the havoc that normal flux may cause, it is somewhat surprising that more energy has not been put into the search for a chloride-free flux. Caillon, a French metallurgist, took a step on the way, for after inspissation in the refining stage, he advocated the use of a chloride-free flux cover. The composition recommended was sodium borate and boric acid. An attempt to repeat his performance in England failed, probably because of the influence of small amounts of impurities in the commercial quality of the ingredients.

After a melt of magnesium alloy has been refined by fluxing at a temperature of about 750 degrees C., the temperature is raised to at least 850 degrees C. and preferably to 900 degrees C. The metal is held at this degree of superheat for 15 mins. and then cooled as quickly as possible to pouring temperature. The beneficial result of the superheating is in the grain refinement of the physical structure, giving, of course, improved mechanical properties. There is not a lot that can be said about this aspect of magnesium melting, for the phenomena have not been satisfactorily explained. One thing, at least, is certain: the effect tends to persist, that is to say, ingots poured from superheated metal give castings of a finer grain even if superheating in the second melting be omitted.

An important result of superheating is that alloys so treated are more amenable to heat treatment than non-superheated metal. This is not altogether unexpected, for the fineness of crystal structure can be readily realized to give speedier solution of the eutectic constituent in the primary constituent, as, of course, there is wider distribution of small "particles" in place of the massive "islands" that otherwise occur. The mechanism of heat treatment will, however, be treated in greater detail in the special section on that subject.

It follows also that castings of fine grain may be more easily machined, although magnesium alloys are in any case so notably free-cutting that such an improvement is not likely to be noticed in practice.

Apart from the less obvious results of superheating there is one visible advantage occurring from the superheating period. The total period between refining and pouring, due to the cycle—refining—heating—holding for 15 mins.—cooling—pouring—is of great value, for time is thereby given for any flux particles that were not completely separated from the molten metal to settle, and this sedimentation does, in practice, occur. Indirectly, therefore, superheated metal gives components of some greater corrosion resistance by eliminating the possibility of dangerous inclusions.



In the present state of knowledge it can truthfully be said that superheating is necessary, for it affects grain refinement and assists in purification, and should certainly be applied as a routine process in the magnesium sand-foundry.

In regard to the preparation of metal for die-casting, the superheating scheme may be slightly modified. It is well known that the quicker solidification rate in a die gives, in any case, a finer-grained material. It is also known that modification of the silicon-aluminium alloys is not as necessary for die-casting purposes as it is for sand-casting. The reason is comparable: modification gives a fine-control structure in sand-castings that is largely secured automatically by the chilling effect of a metal die.

It must be pointed out that the effect of superheating is lost if the metal be held for long periods in the molten condition, and this situation arises, of course, quite normally in die-casting practice where a reserve of metal is made available for more or less continuous casting. The question, therefore, now is: after what period of time should the metal be re-superheated in order to make sure that the metal is of optimum mechanical properties? Only a practical test can furnish the answer. Castings should be fractured periodically; it will probably be found that castings of thin section can be satisfactorily made without additional superheating, whilst thick section jobs may require a secondary superheat. In any case, the degree of superheat for die-casting need not be so high as for sand-casting; probably 850 degrees C. is sufficient.

One final point in this discussion of the theoretical background: the melting loss in magnesium alloys is almost solely magnesium, which appears to oxidize preferentially to the aluminium. The aluminium content therefore increases—a point to be watched when scrap is melted many times.

Now for a step-by-step description of the complete melting process as it takes place in a sand foundry.

The metal charge of ingots and large scrap is placed in a pre-heated iron or steel pot contained within a furnace. Whilst cast-iron pots are suitable, it will be found that fabricated steel pots give much longer life, for the cast variety tends to suffer from casting defects such as blowholes which speedily cause the pot to become unsafe to use. As a matter of routine, melting pots, whether of iron or steel, should be heated to redness before use, and any areas of discontinuous colour should be hammered in order to find weakened portions. Should a dent be easily formed the pot is scrapped. The furnace may be fired by town's gas, producer gas, or oil. Electrical melting in resistance or H.F. furnaces is not yet practised here on any extensive scale.

The metal is in a tested pot and the furnace lighted. To the metal is added a sprinkling of flux. As the bottom metal liquefies and the remaining solid sinks into the bath of molten metal, the surface is maintained inert by a thin flux cover, a little more flux being added when necessary. When the metal is molten the temperature is allowed to rise until a temperature of about 750 degrees C. is attained.

At this stage the heat is cut off. The flux

cover is removed from the metal surface with an iron tool having a shallow spoon-like end. At the same time, by means of a similar tool, the operator sprinkles fresh flux on the surface exposed. Now the metal is covered, flux is added in amounts equivalent to about 3 per cent. of the weight of the metal charge, and allowed to liquefy. When it is liquid it is well stirred into the melt with a heated iron rod of sufficient length to enable the furnaceman to be as far as possible away from the heat. The pot must be vigorously stirred until clean, gleaming metal is seen. There will usually be a certain amount of flux floating on the top, but this is ignored when assessing whether stirring has been sufficient.

At the appearance of bright metal so described, stirring is stopped. Again using the spoon tool, the wall of the pot is scraped down to the bottom, and when the wall has been completely scoured, the flux residue now accumulated at the bottom is removed. The flux residue on the surface is now removed, and the clean metal receives an amount of flux equal to about one-third of that used for refining. This flux is allowed to liquefy and, with an iron rod, assisted to cover the metal surface completely.

The melt is now ready for superheating. The furnace is re-ignited and the temperature increased to about 900 degrees C. It will be found that the flux cover becomes solid as the temperature increases, but protection is still adequate. No burning should be seen during the superheating period. The temperature should be maintained for 15 mins., and as soon as is practicable the pot should be removed from the furnace to allow it to cool as quickly as possible to pouring heat.

A supply of flowers of sulphur should be available in a muslin bag or a tin having a perforated lid. As the pot is carried to the mould, any little burning should be minimized by a shake of the sulphur bag or tin. At the mould position the flux cover is removed, the surface being liberally dusted with sulphur, or dusting compound of the American type. We now have a pot of molten magnesium alloy practically free from flux; if any flux material remains at all, it will be that deposited at the bottom of the pot during superheating. The metal stream during pouring is continuously dusted with sulphur, or, if preferred, with a dusting powder similar to that used in America. In this way, magnesium alloy, even at temperatures exceeding 800 degrees C., may be poured without excessive oxidation.

As a measure of safety the pot should not be entirely emptied into moulds, but should be returned to the melting station to be there emptied into ingot moulds. In this way one can be sure that any flux contained at the bottom of the pot does not accidentally find its way into the casting. The flux residue should be of at least dough-like consistency and, in such a physical state, will be seen to have little chance of flowing with the metal.

Actually, the appearance of the pot after pouring is instructive. It should be clean and free from adherent flux residues on the wall, the presence of which would indicate either insufficient scavenging after the refining stage, or, if a shiny flux is seen, the use of a flux of

incorrect chemical composition. Normally, therefore, the pot is clean and of dry appearance. In this condition the pot may be immediately used again. Nevertheless, after a day's use some amount of dry flux incrustation will appear, and then the pot is filled with water, in order to dissolve or loosen the flux compounds. Quite a vigorous action will be observed together with a noticeable smell of ammonia, due, of course, to the decomposition of the nitride formed during the melting of the metal and the absorption of this compound into the flux during refining.

It is impossible to over-emphasize the need for cleanliness where flux is concerned, and although only one fluxing technique has been fully described—there are other methods dictated by type of flux and personal preference—the fundamental rule is that chloride fluxes must not be allowed to enter the mould with the molten metal.

The melting process for die-casting purposes follows the same general scheme. Two kinds of furnace are used to maintain a supply of metal. In the one case, lip axis, a tilting furnace is used so that the pot may be evenly tilted to pour into a pouring ladle without disturbing the flux cover, which is obviously necessary. The lip of the pot must be kept free from flux particles and oxide, a fairly stiff wire brush being used for the purpose. Only as much metal required to fill the die should be poured at one time, so that metal losses are kept at a minimum. As the metal is used, the flux cover tends to break up, and unless further flux is added burning may take place. It is, indeed, a better plan completely to remove the cover and replace it, rather than to merely patch it, as it breaks. Just to add flux would probably add to the risk of flux contamination, especially if a fairly high temperature is being used.

In the other method of melting for die-casting, a stationary holding furnace is used over which a dome is fitted, into which is fed sulphur dioxide to prevent burning. In this type there is no flux cover, and the ladle is dipped into the metal in the more normal method as used for aluminium ladling. The ladle is of a special design, so that metal runs in over the back edge and is poured from the opposite side. The ladle is hooded, so that as the ladle is filled in an atmosphere of sulphur dioxide, some of the gas is retained in the ladle hood over the metal. The design and use of both the furnace and ladle are covered by patents.

The melting loss on a single melt in sand-foundry conditions should not exceed 5 per cent., while the loss in die-casting foundries is a little higher, 7 per cent. being an average figure.

Magnesium alloys are, in Great Britain, usually melted in comparatively small quantities. In America, however, primary melting is often done in 2,000-lb. furnaces. Such furnaces are used as reservoirs, the metal being melted and maintained at about 700 degrees C. Pouring pots are filled, flux refined and superheated. Whilst it is doubtful if there is any reduction in melting loss, a worth-while advantage certainly accrues: one large furnace occupies much less room in terms of melting capacity per unit area than smaller units normally used, and, when large production is envisaged, metal is always available. It is not necessary, of

course, to empty a furnace used for the purpose of maintenance of a reserve of molten metal; ingot and scrap may be added to keep up the level.

It is seen that magnesium-alloy melting requires a specialized technique, but not a difficult one. It may be profitable to conclude this instalment with some practical details of alloy preparation. Whilst it is true that alloyed ingot is usually bought to specification, the utilization of foundry scrap in the most efficient manner necessitates some knowledge of alloying processes.

The statement was made that the melting loss in magnesium alloy appears to be almost solely magnesium, so that in the melting of small scrap, where losses due to oxidation may be expected to be comparatively high, the proportion of other alloying metals tends to increase. A sample of scrap showing an aluminium content near the top limit may, after remelting, show an aluminium content exceeding that required by the specifications. In the present magnesium alloys, the proportion of aluminium is not very critically defined; it is suggested, therefore, that when the maximum percentage is likely to be exceeded after remelting, admixture of a suitable proportion of pure magnesium or of low-aluminium alloy should be made to the charge. The resultant alloy will, if this be done, have an aluminium content about mid-way between low and high limits.

The remaining alloying metals in the present alloys are zinc and manganese. Zinc seldom exceeds 2 per cent., and it is not necessary as a rule to adjust its content. Manganese is present in the casting alloys in the order of 0.2-0.3 per cent. in order to improve corrosion resistance. Again, there is seldom need to adjust the content of this element: when necessary, however, it is added by means of manganese chloride, which is reduced to metallic manganese by molten magnesium, or in the form of aluminium/manganese hardener.

The chief impurities in magnesium alloys are iron and silicon. It is true that the American work stressing the importance of impurities was in relation to super-pure metal, but there can be no doubt that it is desirable to keep impurities to a minimum to maintain the maximum physical properties and highest corrosion resistance.

Iron pick-up is not very noticeable even after many remeltings, but the proportion does, nevertheless, increase. It may be said that iron content should not exceed 0.02 per cent., and when this figure is likely to be exceeded, suitable proportions of new ingot should be added to the charge.

Silicon may be introduced by the use of sand-contaminated foundry scrap. Runners, in particular, and risers should be sand-blasted before use. Die foundry scrap may be used without this treatment. Silicon should not exceed 0.2 per cent.; amounts greater have a deleterious effect on mechanical properties.

On the score of ease of storage and certainly of alloy composition, a case can be made for the melting and ingotting of all scrap, the amount of its use depending upon the result of subsequent chemical analysis.

*(To be continued)*

# NEWS — General, Technical and Commercial

## "Healthy Industry"

PUBLISHED by the Automatic Telephone and Electric Co., Ltd., under the title "Healthy Industry," has appeared a 52-page booklet summarizing the experiences gained by the company during the past few years in connection with industrial medical welfare.

It will be expedient, first, to summarize the section headings. These are as follow:— Introduction; the working of an industrial service established during the war; absenteeism and its significance; national statistical researches; charts and graphs; absence recording system; conclusion.

A subsection, entitled "Survey of Clinical Work," is of immediate general interest; hazards consequent upon the use of benzyl alcohol, carbon tetrachloride, and a synthetic insulating material are here reported upon, together with a survey of the septic rate of accidents reported in connection with light alloys. It appears that "a cutting wound in operators using certain light alloys rapidly turned septic. The research laboratory was approached and its report showed that these substances con-

tained magnesium which, even in small quantities, in this case less than 1 per cent., caused a virulent infection similar to gas gangrene. The co-operation of the foreman was sought to enforce immediate attendance at the first-aid room for the most minor cuts. Instructions were given to the nursing staff to remove all minute particles of metal after thoroughly irrigating the wound. The septic gases from this source were then considerably reduced."

The wording of the paragraph in this connection is somewhat unfortunate, and tends, we believe, to create an entirely false impression of the cause and gravity of so-called "poisoning" by magnesium and magnesium-bearing alloys. The subject is complex and formed the basis of a detailed survey presented in "Light Metals," 1939/2/210. It is, we believe, essential that a distinction be made between the specific toxicity associated with many organic compounds used in industry, and with salts of chromium, and the apparent toxicity of a metal such as magnesium where, in fact, no true poisonous properties exist, although, as a result of gas generation in the tissues unpleasant secondary symptoms may arise.

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## FLUX FOR FLAME WELDING OF MAGNESIUM

THE flame welding of magnesium or magnesium alloy demands the use of specially developed fluxes. These comprise properly balanced mixtures of halides of the alkali and alkaline earth metals and all suffer from the drawback of deliquescence. Whilst they meet all the requirements of fluxing for the flame welding operation, this characteristic of quickly attracting moisture definitely adds to the degree of undesirable attack upon the base metal, both in the interval between fluxing and welding, and that between welding and subsequent flux removal by washing processes. The first of these can be catered for at the most by fluxing and welding in quick succession, and the second by making the washing operations follow welding immediately. The latter in particular is not so obviously practicable as it sounds, for example, when much welding is being performed in continuous

sequence on the same structure, or when a number of members are being welded intermittently to one assemblage.

The name of Mike A. Miller, associated with the Aluminum Co. of America, is well established in connection with fundamental studies on the brazing of the aluminium series of light alloys. Especially is he regarded as an expert on dip and furnace brazing in all their aspects, and he is known for the series of informative patent specification covering a series of fluxes designedly developed for these operations upon the aluminium alloys. It is not surprising, therefore, to find that Miller has also given his attention to fluxes for the fusion joining of magnesium and its alloys. U.S. patent specification No. 2,296,396, September, 1942, on this subject is due to him.

By fusion joining, Miller refers to those joining processes in which localized fusion

of at least a portion of the metal that joins the structural members occurs. By the term magnesium, he embraces both pure magnesium and alloys containing at least 50 per cent. by weight of that alloy.

A film of reaction product is always present on magnesium surfaces exposed to the atmosphere because this metal is very active, being readily attacked by the air and salts. This makes the joining of magnesium components difficult, and the superficial corrosion products must be removed before joining can efficiently be achieved. For the sake of brevity, Miller refers to the surface film as oxide, and the processes by which it is formed as oxidation. For the production of a sound joint, a flux has to be employed that will produce disintegration and dispersion of the oxide film and of any foreign matter that adheres to it. When the removal of the film is not complete, adverse results are obtained. These may be revealed by the admixture of oxide particles with the fused metal, by porosity and by reduced corrosion resistance if the oxide particles occlude flux with them; further, areas where oxide is not properly removed cause uneven flow of the fused metal, weak joints in consequence, and the absence of a continuous metal-to-metal bond at the interface of the filler metal and the parent metal.

The object of Miller's patent is to provide a flux that contains lithium chloride, and yet does not react to an appreciable extent with magnesium in the presence of moisture. The features aimed at may be summarized as under:—

(a) To provide a flux containing sufficient lithium chloride to ensure proper action of the flux on the magnesium surface.

(b) To provide a flux that may be easily applied to the magnesium surface and left in contact with it for reasonably long periods of time without interfering with the subsequent fusion joining operation.

(c) To provide a method of joining magnesium members using the conventional chloride fluxes without the usual deleterious action upon the metal prior to the fusion of the flux.

(d) To provide a means of increasing the speed with which fusion joints can be made when using fluxes containing lithium chloride.

(e) To provide a flux that does not cause a large amount of oxide when it is applied to magnesium, and yet when

fused efficiently removes the oxide coating from the magnesium surface and causes the molten metal to spread evenly to form a smooth, well-filled joint, free from blisters and inclusions.

To these ends, Miller claims the discovery that very small amounts of chromates and dichromates, when added to lithium chloride containing fluxes which also contain water, produce mixtures with which there is virtually no reaction at room temperatures between the flux and the magnesium in the interval between applying the flux to the metal and time the flux is fused in the joining operation. At the same time, there is no undesirable oxidation of the metal or interference with the proper joining of the members. A lapse of eight hours or more is permissible between the time of applying the flux and that of carrying out the weld. This is a relatively long period compared with anything permissible in the ordinary way. The speed of making the fusion joint is increased under these conditions.

A range is given from which particular mixtures can be formulated for good welding results on magnesium components:—

Lithium chloride: 5 to 30% by wt.

Alkali metal fluoride: 3 to 15% by wt.

Alkali metal chloride: 5 to 50% by wt.

Second alkali metal chloride: 5 to 50% by wt.

Chromate or dichromate: 0.01 to 0.2% by wt.

Further, a closer range for the particularly desirable flux is also quoted:—

Lithium chloride: 10 to 15% by wt.

Lithium fluoride: 4.5 to 7% by wt.

Sodium chloride: 5 to 50% by wt.

Potassium chloride: 5 to 50% by wt.

Chromate or dichromate: 0.05 to 0.01% by wt.

The melting point of the flux for welding magnesium should generally lie between 1,000 degrees F. and 1,180 degrees F. in order to ensure melting below the melting point of magnesium (1,202 degrees F.) or that of the filler alloy, and to ensure effective cleaning and protection of the metal. The composition of the flux mixture should therefore be adjusted accordingly to give the best melting point. For most magnesium articles, a flux for welding having a melting point about 1,050 degrees F. will generally be satisfactory. For types of joining other than welding, a further adjustment of composition in order to give the suitable melting point may be necessary.

### Moulded Screw Threads

**B**ECAUSE of the close association between developments in the light metal and plastics industries, we have great pleasure in noting the publication "Tolerances for Screw Threads," by J. Butler, Development Engineer, British Industrial Plastics, Ltd., by whom the paper is issued.

From the standpoint of the metal user, much of the matter contained here is not of specific importance; sections 4 and 5, however, dealing respectively with moulded female threads mated with standard metallic bolts, and moulded male threads mated with metal female threads, are of especial interest.

Factors governing the accuracy of screw threads moulded in plastic materials differ markedly from those encountered in general engineering practice with metals, and the author, in section 4 referred to, pays particular attention to pitch shrinkage, length of engagement, and defect of shrinkage fluctuations on pitch. Sketches, tables and monograms contained in this paper are likely to prove of the greatest value to those dealing with composite assemblies.

### Steel Prices and Costs

**U**NDER the title "Steel Prices and Costs," the British Iron and Steel Federation has issued a 19-page brochure based on extracts from the national Press. The purpose of the publication is to put forward the iron and steel point of view on the recent steel prices controversy.

Although, as the issuing body states, the booklet does not present a complete picture of the very complicated problem with which the industry is faced, it does, nevertheless, ensure that the bulk of the relevant matter is available in a readable form. All unwarrantable speculation, and vague unsubstantiated statements, can readily be put to test by consulting the extracts referred to here.

### Mechanical Properties of Magnesium

**A**TENTION is drawn to the July issue of "Magnesium Review and Abstracts" on pages 65-94 of which appears an account entitled "Notes on the Mechanical Properties of Magnesium Alloys at High Temperatures—A Survey of Available Data," by P. A. Fisher.

The author is to be commended for the thoroughness with which he has analysed his sources, and for the frank comments he has embodied in the concluding section of the work. The review is ably illustrated with numerous graphs and all important matter is clearly tabulated.

### Prefabricated Houses

**M**ANY Sunday papers, a week or so ago, gave wide publicity to the following cable from Reuter's Washington Correspondent Paul Scott Rankine: "America is making plans to build thousands of prefabricated aluminium houses . . . to replace Britain's blitzed homes. . . . If Britain decides to import them they will be in production shortly, as the aircraft factories become unessential to the war effort."

Now there is no denying that our allies in U.S.A. have done us and the world an immeasurable service by the aid they have given in pushing forward our war-time aims, but this aid, no less than reverse lend-lease, must, like the war itself, be considered as an extra-economic factor requiring most careful supervision and control. True, we need prefabricated houses, but what of our own aircraft and aluminium industries?

Relative to the delicate argument we embark on here, is the recent London cable from J. H. Van Deventer, President and Editorial Director of "The Iron Age" (featured editorially in that journal for October 5, 1944). Mr. Van Deventer confined his discussion to steel, but the implications extend far beyond this one material.

We have in this country a superabundance of light metal. Mr. C. W. Devereux recently estimated, for example, that we had half a million tons of aluminium in hand besides the necessary plant, technicians, and an army of a million craftsmen skilled in the work of light alloys. Why, then, should we not undertake the building of our own houses in our own aircraft factories?

It is more or less common knowledge that movements have already been made in this direction. The Aircraft Industries Research on Housing Committee (composed of representatives of both the light metals industry and the aircraft industry) has designed a bungalow already in the course of construction. This assembly, it is interesting to note, is a preliminary to the evolution of a permanent two-storey house.

The criticism we voice here is not in any way conceived in a narrow national limit. Rather, we feel that, with the resumption of normal world trade during the early post-war period, every effort must be made from the outset to achieve some common-sense balance. Bitter lessons learnt after the close of the 1914-1918 war taught us all that the easy quick solution to temporary difficulties which always beset us on occasions like these is, in the long run, by no means necessarily the best.

### Standards for Screw Threads

THERE has recently been published a report on Conferences between engineers of the United States, Canada and Great Britain, which took place in New York at the end of 1943 and in London in August and September, 1944, on the subject of United States and British Standards for Screw Threads and Limits and Fits for Engineering.

The main difficulty experienced in America in the production of the Whitworth form of thread concerned the rounded crests and roots, involving special tooling problems which do not arise in connection with the American thread. To avoid this difficulty the American Delegates to the Conference proposed the adoption of the truncated form of Whitworth thread. The British Mission was able to advise as to the desirable tolerances applicable to this modified thread and it was agreed that American and British Specifications should be produced on common lines to cover the truncated Whitworth thread.

During this Conference the opportunity was taken to discuss other screw thread problems which affected the production of equipment for the war effort in the three countries and a number of projects were initiated which, when carried forward, would result in incalculable savings in material, in man-power and in the time required to commence production. The most important of these related to the desirability of devising a common standard for screw threads, both as regards the form of the thread and the commonly used series of diameters and their related pitches. In this connection it was agreed that the matter should be actively considered in the United States, Canada and Great Britain, with the object of further discussions.

The results of these Conferences have been published in a report issued by the C.P.R.B. in the United States, Canada and Great Britain. Copies of this report can be obtained from Director-General of Machine Tools, Ministry of Production, Dept. D.G.M.I., Caxton House East, Tothill Street, S.W.1.

### Death of Mr. Henry Morgan, F.S.A.A.

ON Friday, November 3, 1944, died Mr. Henry Morgan, F.S.A.A., Chairman of Siemens-Schuckert (Great Britain), Ltd.

Mr. Morgan's death severs a long-standing association with a company which has pioneered so many developments in electro-technology.

### Science and the Future

ORGANIZED by the Association of Scientific Workers, a conference to discuss the use of science in the post-war world will be held at the Caxton Hall, London, S.W.1, on February 17-18, 1945. Its purpose is to draw attention to the need for science to be used as fully in peace time as it has been during the war.

In the earlier conferences, the Association has dealt with the integration of science in the war effort, the need for more central planning and for more use of the initiative of the younger working scientists. With the approaching victory of the United Nations, it is necessary to show in practical terms what science and technology can do to provide the basis for an expanding world economy, and to satisfy the material and cultural needs of the people of the world. The power of science must be fully used by the community; if fully used a richer world can be achieved than we have ever known before.

Further particulars will be issued later, and may be obtained from the Association of Scientific Workers, Hanover House, 73, High Holborn, London, W.C.1.

### British Electrical Engineering Co., Ltd.

WE are informed that on October 21 Mr. F. S. Mitman, C.B.E., joined the board of the British Electrical Engineering Co., Ltd.

Mr. Mitman is a graduate of the Lehigh University, U.S.A. (Degree of Engineering Mines, 1923). For a number of years he was associated with the light-metal industry and, since 1939, has held the following appointments:—Director of Light Alloys and Magnesium (sheet and strip control), Ministry of Aircraft Production (1939-1941); Co-ordinator of aircraft supplies for fighter and naval aircraft, Ministry of Aircraft Production (1939-1941); Adviser on light metals fabrication, Ministry of Aircraft Production (1941-1942).

Since 1942 Mr. Mitman has been Chairman and Managing Director of Messier Aircraft Equipment, Ltd., with which company he is retaining his connection.

### Zinc Development Association

WE have received from the Zinc Development Association a report covering the period 1943-1944. Within the space of eight pages the service offered by the Association and the work it has already undertaken are ably summarized. The final page is devoted to a list of recent publications which are available on request.

### Magnesium Mosquito Door

PAGE 36 of "Light Metal Age" (U.S.A.) features a brief note on a magnesium mosquito door installed in Castle Harbour Hotel, Bermuda. It is reported that this door, which has been in service since 1937, is still in use and is still giving every satisfaction, in spite of the fact that it is exposed to all the rigors of a maritime climate.

To the note as presented by our American contemporary, we would add this further detail, that the door was constructed by J. Starkie Gardner, Ltd., Merton Road, Wandsworth, London, S.W.18.

### Aluminium Scrap in U.S.A.

IT is reported that the non-ferrous scrap metal market in U.S.A. underwent, in July, an all-round slump, and dealers' stocks increased markedly. Sales fell 146,697 tons in June to 11,556 tons in July, the smallest monthly total since December, 1943. Dealers' stocks rose to 38,523 tons compared with 35,688 tons in June.

On July 31, 1944, the following stocks were in hand:—Sheet and clippings, 8,232 short tons; castings and other heavy scrap, 5,655 short tons; swarf, 8,460 tons; wrecked aircraft, 8,417 tons; unclassified aluminium scrap, 7,759 tons.

### Gauge and Tool Export Drive

EARLY this year, the Council of the Gauge and Tool Makers' Association decided to appoint a committee whose broad terms of reference would be to consider all matters connected with the export of British tools and gauges, and the first meeting was held on March 16, 1944. Mr. H. Madeley, Sales Director of The Brooke Tool Manufacturing Co., Ltd., was appointed chairman of the committee.

Since that date, the Export Committee has met regularly at least once a month, and sometimes more frequently, the meeting in April being attended by Mr. D. H. Lya', C.M.G., M.B.E., a Director of the Department of Overseas Trade, who gave the members the benefit of his advice on various aspects of post-war export business; and close collaboration with the D.O.T. and Board of Trade has been maintained. The D.O.T. has, in fact, asked the committee from time to time for additional copies of its reports, and has expressed the desire in writing to be informed of the Association's export activities.

The committee has met the trade coun-

sellors, consuls and commercial attaches of a number of Empire, Dominion and foreign Governments in order to ascertain their countries' post-war requirements of British tools and gauges and the best methods of supplying such needs. Interviews have taken place at the Argentine, Australian, Belgian, Brazilian, Chinese, Dutch, Egyptian, Norwegian, Portuguese, Russian, South African, Spanish, Swedish, Swiss and Turkish Legations in London, and much valuable assistance and information were obtained. The representatives of the Export Committee were in every instance most cordially received, and were given advice on questions such as the appointment of qualified and reputable agents, the most suitable engineering journals in which to advertise, and ways and means of improving the service hitherto offered by British exporters. Introductions were secured to various commercial houses, syndicates and industrial centres overseas; and, at their own requests, the Legations were all provided with duplicate copies of the catalogues, price lists and other trade literature issued by the members of the Association in order that one consignment could be retained for the information of the Legation in London and the other sent to the Government headquarters in the country concerned. Similar talks will shortly be held with the Canadian, Czecho-Slovakian, French, Italian, Greek and Palestinian Embassies.

Many of the trade counsellors and commercial attaches were quite frank in their criticism of British export service, and stressed the need for improvement if Great Britain was to meet competition successfully from other exporting countries after the war. Emphasis was laid upon the importance of having catalogues, etc., translated into the appropriate foreign languages instead of merely sending them overseas in English; and the Export Committee was urged to recommend members of the Association to send out men of director status and technical ability who would converse reasonably fluently in the language of the particular country. It was also pointed out that many British exporters were only prepared to quote F.O.B. prices, whereas the Americans, Germans and Swedes gave C.I.F. figures; and, in short, it was clear that British manufacturers must devote greatly increased attention to market research and be ready and willing to meet the exact requirements of the overseas buyer. *The pre-war tendency towards a "take it or leave it" attitude will not do if Great Britain is to regain her export markets.*

### Aluminium Gravity Dies

SOME few weeks ago, an exhibition was held to demonstrate the Parlanti Mould Process (B.P. 543,577). Briefly, the process is one of gravity die-casting which, instead of employing the customary steel mould, makes use of one in aluminium; for the purpose the mould is anodized.

The process presents many notable deviations from the customary gravity die-casting system. In place of the various machining operations required for iron and steel moulds, Parlanti moulds may be sand-cast direct from plaster patterns. Accord-

resultant structure being so dense and homogeneous that it may be worked up directly for optical reflectors. The exclusive licensees of the process in Great Britain are United Aluminium Foundries, Ltd., 9, Beaumont Avenue, West Kensington, London, W.14.

### Metal-forming Machinery

IT is announced by A. C. Wickman, Ltd., Coventry, that the company has been appointed sole agent and engineering representative in the British Isles for Yoder High Production Metal Forming Machinery manu-



GENERAL view of the Parlanti Mould Exhibition recently held in London. Displayed here were various typical castings designed to demonstrate the special merits of the process. Anodized aluminium moulds and plaster patterns were also to be seen. This general exhibit was run concurrently with a demonstration of the process under actual working conditions.

ing to the exigencies of production, mould production may, if necessary, be still further speeded up, and, because of ease of manufacture, numerous moulds can be cast to a given form.

The "equilibrium" operating temperature of the Parlanti mould is 100 or more degrees Centigrade below the "equilibrium" operating temperature of the steel mould. Chilling effects, which are of a highly specialized type, are very intense, with the consequent production of exceedingly fine grain size; hence, marked improvements in all mechanical properties.

It is not proposed in this brief note to discuss the more intricate aspects of the process, but some insight is given by the fact that it is possible in a light-metal mould to cast 99.99 per cent. aluminium, the

factured by the Yoder Company of Cleveland, Ohio, U.S.A.

In the range of machines manufactured by the Yoder Company are cold roll forming machines, complete tube mill, rotary gang slitters and side trimmers, flying cut-off shears, sheet-metal coil handling equipment, plate levellers, high-speed power hammers, and various special metal-forming machines such as brake-shoe bender and garnish moulding bender.

### New B.N.F.M.R.A. Appointment

THE British Non-Ferrous Metals Research Association has appointed Mr. G. L. Bailey as director to succeed Dr. H. Moore, who retired from this post on October 31.

Mr. Bailey graduated in metallurgy at



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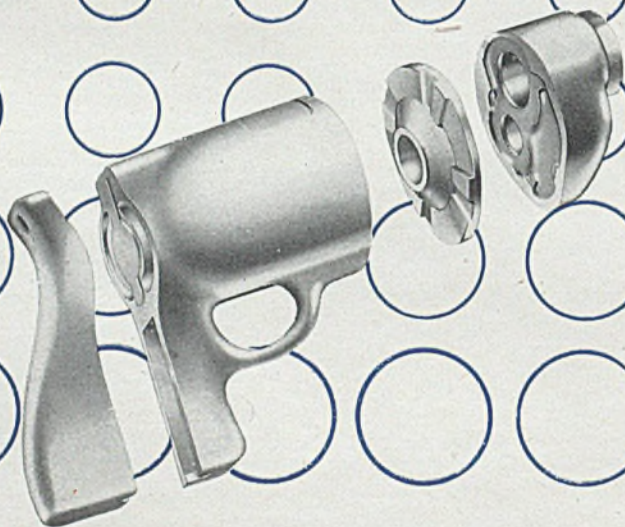
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Birmingham University, where he was awarded the degree of M.Sc. in 1922, after completing two years' research work. From 1922 to 1930 he was on the staff of the research department, Woolwich, where he carried out research on a variety of problems in non-ferrous metallurgy. During this period his most notable work was on the casting of 70/30 brass ingots for subsequent rolling, the results of which were published by the Research Association in a monograph "The Casting of Brass Ingots," under the joint authorship of Dr. R. Genders and Mr. Bailey.

In 1930 Mr. Bailey resigned from the Woolwich research department to accept the appointment of development officer of the British Non-Ferrous Metals Research Association. In this post he was responsible for fostering the application of the results of the Association's researches in industry. He played, however, a wider part in the Association's organization, and in January, 1942, became deputy director.

Mr. Bailey is a vice-president of the Institute of Metals and chairman of the London Local Section of that Institute. He is well known in the metals industries and in metallurgical circles as one of the leading scientific men in the non-ferrous metals field.

### New Aluminium Alloy

THE Reynolds Metals Co., U.S.A., has brought out a new aluminium alloy, which is now being used in war aircraft. Known as R-301, it was the result of laboratory work by one of the Reynolds' metallurgists, Thomas L. Fritzen.

The company describes R-301 as offering several marked advantages over currently used aluminium alloy, such as 24S sheet. Three of these advantages are given as follows:—

1. Excellent formability in the annealed and solution-heat-treated tempers.
2. Minimum yield strength of about 40 per cent. higher than present alloys.
3. A harder and more scratch-resistant surface.

Sheets and plates are designated R-301. The various tempers are as follows:—Annealed, R-301-O; solution-heat-treated, R-301-W; solution and precipitation-heat-treated, R-301-T. The sheet and plate consist of a high-strength core alloy covered on each face with a corrosion-resistant intermediate strength alloy. Percentage of alloy cladding varies with the gauge of sheet.

Whilst R-301 is described as containing the same elements as in 24S alloy—silicon, iron, copper, manganese and magnesium—its physical characteristics differ. Typical properties are:—

|             | Tensile.<br>Tons/<br>sq. in. | Yield.<br>Tons/<br>sq. in. | Elongation.<br>per cent<br>in 2 ins. |
|-------------|------------------------------|----------------------------|--------------------------------------|
| R-301-O ... | 11.2                         | 4.7                        | 22.0                                 |
| R-301-W ... | 27.7                         | 18.3                       | 19.0                                 |
| R-301-T ... | 30.3                         | 26.9                       | 10.0                                 |

The company says that it is planned to increase the properties of the different tempers from present maximums. For example, R-301-O would be given a tensile strength maximum of 13 instead of 11 tons/sq. in. R-301-W would be built up to a minimum of 25 tons/sq. in. for 0.030 in. and less and 25.4 tons/sq. in. for 0.040 in. and thicker. R-301-T will be made with 28 tons/sq. in. minimum for 0.039 in. and thinner, with 28.4 tons/sq. in. for 0.040 in. and heavier.

When the new alloy is annealed to relieve work hardening, it is usually soaked at 337-348 degrees C. for one hour. When hardening is caused by partial or full heat treatment, it is soaked for two hours at 393-404 degrees C., which is followed by cooling at a rate not to exceed 10 degrees C. per hour up to 316 degrees C. Precipitation-heat-treatments require six hours at 177 degrees C. on finished parts and 18 hours at 160 degrees C. when further dimpling or forming is required.

### Therapeutic Value of Aluminium

FOLLOWING a dozen years of research into prevention and cure of silicosis, a project sponsored by McIntyre-Porcupine Mines, Ltd., Schumacher, Ont., Canada, and the University of Toronto, a recent report indicates possible success in the use of powdered aluminium as a preventive agent.

The studies were conducted at the university by Dr. J. J. Denny, Dr. W. D. Robson and D. A. Irwin (now with Aluminum Co. of America). During the research a study of worker health at the Aluminum Co.'s New Kensington works in the U.S. indicated that some 125 workers with finely powdered aluminium for paint and ink had somewhat better health records than the rest of the 3,000 workers in that plant.

Finely powdered aluminium was tried out on silicosis victims. The theory of silicosis is that the silica in the lungs is transformed slowly into dangerous silicic acid by the body fluids. This acid causes scar tissue on

the lungs. The aluminium dust, however, tends to form a protective coating over the silica dust, preventing it from dissolving. As a preventive of silicosis, workers at the McIntyre-Porcupine Mines have a fine spray of aluminium dust projected into the room where they change their clothes before going to work. The clothing-change requires about 10 minutes, so that each worker inhales a small amount of aluminium dust to protect his lungs against the silica.

### Acheson Award to Blum

NEWS has been received that Dr. William Blum, chief of the electro-chemistry section of the National Bureau of Standards in the U.S., has been designated as this year's recipient of the Edward Goodrich Acheson Medal and \$1,000, awarded every two years to the "person who shall have made a distinguished contribution to the advancement of any of the objects, purposes, or activities of the Society." The Society is the Electro-chemical Society.

Dr. Blum, who joined the National Bureau of Standards in 1909, has done important analytical work on sodium oxalate as a primary standard in volumetric analysis, the titration of manganese and the gravimetric determination of aluminium.

### Solar-searchlight Reflector

REFLECTIVITY of aluminium has long been recognized by makers of lighting fixtures; now the General Electric Co. has developed a solar searchlight for shipwrecked mariners and others to signal searching aircraft or distant ships. It is pocket-size, with a mirror consisting of a small rectangle of tempered and polished plate glass, with smooth chamfered edges and rounded corners. It measures only 4 by 5 ins. and weighs less than 8 oz. The mirror may be securely suspended from a man's neck with a braided lanyard looped through a corner hole. Rear surface of the glass carries a thin film of vaporized aluminium of high reflectivity. This forms the main mirror and a rounded rear mirror. A central aperture in the glass in the form of a cross is left clear. All edges and the rear, except for the small round mirror, are coated with black lacquer, on which is printed the instructions for use. Edges and the entire rear are sealed with clear lacquer.

These mirrors are described as reflecting a large portion of the incident sunlight with a reflection factor between 80 and 85 per

cent. or about 30 per cent. higher than the reflectivity of chromium plating. Under the most favourable sunlight conditions, the beam candle-power appears to be close to 15,000,000 or 16,000,000.

In aiming to reflect a beam that will be noted by an aeroplane or distant ship the user positions the mirror to face a point about half-way between the sun and his target, and picks up the image of the sunlit cross (aperture in centre) in the round rear mirror. He sights the target through the centre of this cross. Conditions for accurate aiming are completed when the mirror is tilted to superimpose the image of the spot on the aperture and the target.

### Device to Measure Thickness

THE "sonigage," developed by the Research Laboratories division of General Motors Corp., has been used successfully for electronic measurement of thickness of parts fabricated from aluminium, steel, brass, copper and silver. It is being applied to measurement of critical thickness of various aircraft parts after final machining.

The new electronic device, originally applied to measuring hollow steel aircraft propeller blades was described at the recent S.A.E. National Aeronautics meeting in New York by Wesley S. Erwin, of G.-M.'s research division. It consists of a simple variable-frequency electronic oscillator and X-cut quartz crystal transmitting mechanical vibrations to metal. A power output meter shows the metal's resonant frequency.

As the product of resonant frequency and thickness is equal to one-half the velocity of sound (constant for any metal) frequency and thickness are inversely proportional, and the device can measure thickness from vibrations in the 0.020 to 0.400-in. range, with a maximum error of less than 2 per cent.

The device is described as simple in operation, requiring no special skill, and Erwin suggested it should be applicable to many uses where rapid inspection of parts is necessary. To use the "sonigage" the quartz crystal, which is 1-in. square and 60/1,000ths of an inch thick, is placed in contact with the metal. The oscillator dial is tuned to the resonant frequency. Power supplied by the oscillator maintains resonant thickness vibration against the internal damping of the metal. The power-output meter indicates the metal's resonance point sharply.

## Engineering Precision Measurements

WRITTEN by A. W. Judge and published by Chapman and Hall, Ltd. (25s. net), the treatise, "Engineering Precision Measurements," represents a further stage in the general diffusion throughout industry of the scientific, as opposed to rule-of-thumb, method.

In the space of some 310 pages, the author has compressed a vast amount of data, well illustrated and so linked together as to present for all its numerous facets an appearance of pleasant continuity.

The bulk of the book is divided into nine chapters dealing respectively with linear measurements, instruments and indicators, micrometers, verniers and measuring machines, limit profile and slip gauges, screw thread measurements, internal measurement methods, measurement of angles, comparators, other optical measurement methods, special methods and appliances. The book concludes with two appendages and an index. It is essentially practical in outlook and treatment and should appeal not only to the fully trained engineer, but to all apprentices and students in the various branches of engineering science.

## Pattern-making for Gears

THE author of "Pattern-making for Gears"—G. Offiler (Charles Griffin and Co., Ltd., price 7s. 6d. net)—has presented us with a severely practical but eminently understandable and readable book. Within the compass of some 166 pages he pilots us through the intricacies of pattern production for angular bevel gears, bevel gears, internal gears, mitre gears, spur gears, worm wheels and worms.

His knowledge of the science and craft required in this branch of industry needs no added testimony from ourselves. The book may desirably replace many of the older and out-dated works at present occupying valuable space in our bookshelves.

## Metallography of Magnesium

THE translation by the technical staffs of F. A. Hughes and Co., Ltd., and Magnesium Elektron, Ltd., of the original German book by Walter Bulian and Eberhard Fahrenhorst, on the metallography of magnesium and its alloys, comes as a corollary to their translation of Beck's book, "Magnesium and Its Alloys." Published by F. A. Hughes and Co., Ltd., at a time when our thoughts are turned to the post-war

applications of light alloys which have played such an important part during the war, this translation forms a very useful contribution to the somewhat scanty information of the microstructures encountered in the magnesium alloy field.

The authors show how microscopical examination can be used to reveal the type of alloy, to obtain information as to the treatments it has received, and to ascertain the nature of any defects the material may contain. The methods used for the preparation of microsections and the etching reagents employed for revealing certain features are briefly described. Magnesium alloys are divided into two broad groups—those which do not contain aluminium and those in which aluminium is present as an alloying constituent. Pure magnesium and binary magnesium-manganese alloys are included in the first group and the magnesium-aluminium-zinc alloys in the second. The microstructures of the common alloys in the sand-cast, die-cast, extruded, forged and rolled conditions are described. The effects of additions of cerium, calcium, iron and silicon are indicated, and reference is made to the preferential chemical attack in the direction of the basal plane and its effect on the course of corrosion in the pure metal and its alloys.

The book is adequately illustrated by over 200 micrographs which have been selected from a collection of four times that number taken by the authors in the course of their investigations in the laboratories of Wintershall A.-G. In some cases the authors have used oblique illumination to advantage in order to illustrate certain structural features not so easily revealed by normal vertical illumination. The authors have appended a list of over 100 references, chiefly to works of German origin, to which the translators have added a further list to include the more recent publications by British and American authors.

"Metallography of Magnesium and Its Alloys" is full of information of the kind which has so long been required by workers in the light-alloy field. It covers the whole range of magnesium-rich alloys which are at present in use, and the translators' hope that "this work will prove to be of value to all those interested in magnesium alloys and in metallography" is well justified.

## Light-alloy Specifications

Additions and corrigenda to the tabulated summary of light-alloy specifications, published in "Light Metals" for December, will be noted in our February issue.

# Aluminium and Magnesium in the Electrical Industries

*Continuing his Account from "Light Metals," 1944/7/479, the Author Discusses, in this Instalment, Difficulties Encountered in the Clamping of Steel-cored Aluminium Cable and the Results of Russian Research in this Regard*

By

B. J. BRAJNIKOFF

FROM a general account of transmission lines, which has already been given, it may be readily deduced that the design of aluminium conductors for high-voltage overhead power systems constitutes a complex technical problem. According to considerations put forward in the preceding section, it is evident that careful attention to the structural aspects of the clamps for securing aluminium cables to the line supports is of paramount importance in order to minimize, as far as possible, chances of mechanical failure of the line. This part of the structure has a vital bearing not only on the serviceability of the conductors themselves, but also on the type of supporting towers and their spanning, and thus on the reliability of the entire system.

### Design of Clamps

We shall now, therefore, approach the subject still more closely, making use of data revealed by recent research, and in the light of results obtained under actual service conditions.

Take an overhead line, the supports for which are designed to withstand the simultaneous rupture of two conductors in one single span. When it is remembered that, owing to great spans, heavy cables and long cross-arms for carrying them on the line supports, the failure of even one conductor will result in such severe torsional stresses as to lead to the collapse

of the mast, it is easy to see that if the cables be fixed rigidly in the clamps, the forces acting upon the support in the event of breakdown of two conductors, being of the order of several hundred kilograms, implies a structure for the supporting tower of a very heavy and costly type.

### Merit of Sliding Type

This circumstance, naturally, urged designers to seek new ways and means of reducing stresses resulting from rupture of the conductors. For the purpose, various types of supports with an increased flexibility, as well as different methods for securing the cables to the clamps, were suggested. Thus, on the one hand, there have been designed special metal supports fitted with turn-brackets, thereby attaining stress reduction, at the moment of cable failure, up to 15 to 20 per cent. On the other hand, there have appeared novel types of clamps, capable of disengaging the conductor when the tension in it exceeds a certain specified value. As a result of this, the cable slides in the clamp, thereby equalizing the tensions in neighbouring spans and, consequently, releasing to a considerable degree the supporting mast of critical stresses, which otherwise might lead to breakdown.

In this field of special interest are the "TT" type of the line supports made of

wood, designed to give increased flexibility, and also the slide clamps as recently adopted on some of the heavy duty lines in Russia. These clamps, by allowing the cable to move freely in the case of any excess tensions in the line, were able, practically, to guard the support almost completely from overstressing. As a consequence, there have been achieved very appreciable economic advantages in the construction of transmission lines. It became possible to increase span lengths up to 200 to 225 metres, and simplify the erection of conductors. Thus the total construction cost of one kilometre of high-voltage overhead line could be reduced by 15 to 20 per cent.

#### Difficulties with S.C.A.

However, all these advantages accruing from the application of slide clamps were associated with the use of copper conductors. In attempts to utilize such clamps in connection with steel-cored aluminium cables, it has been found that they are totally unsuitable on account of the likelihood of serious damage to the softer metal; the designers, then, were again confronted with the original problem of erecting the line supports for the conductors attached by means of the clamps of a fixed type, necessitating stronger supporting masts. Hence the cost per kilometre of a single-circuit line at 110 kv. calculated for an equivalent conductivity (for example, with copper of 95 mm.<sup>2</sup> cross-section, and, corresponding to this, 193.7 mm.<sup>2</sup> for steel-cored aluminium), was found to be higher for steel-reinforced aluminium cables than that for copper conductors.

If we neglect a slight increase in structural weight of line supports due to a higher wind pressure, which is inevitable as the diameter of steel-cored aluminium cable is approximately 1.5 greater than that of the copper conductor, it is to be expected that, in the event of erecting steel-reinforced aluminium cables in slide clamps, the same values of cost would result for one kilometre of the transmission line as for those employing copper conductors. Hence, in this case, the

structure of the supports would not require any serious modifications, but would allow the utilization of the supporting masts designed for copper conductors, by merely replacing the latter by steel-cored aluminium cables, and, keeping the same span, only stiffening the mast by means of two diagonal ties. Thus, depending on the relative prices for copper and aluminium, this method introduces economic advantages on the part of steel-reinforced aluminium cables. It is clear that the successful solution of this problem directly depends as to whether or not it is possible to construct a suitable slide clamp for steel-cored aluminium cable.

The fundamental requirements to which the design of any slide clamp should conform, irrespective of the conductor material which it has to support, may be formulated as follows:—

(1) The wear of the conductor in the clamp must be reduced to a minimum.

(2) The effort necessary to move the conductor in the clamp should have a sufficiently large value in order to avoid constant displacement of the cable and, consequently, its excessive wear.

(3) The value of this effort should not be so great as uselessly to increase the loading of the line support at the moment of rupture of the cable.

(4) One and the same clamp should be able to accommodate conductors of various cross-sections, i.e., it must be of universal application.

#### Special Wear Problems

When the problem of adopting copper slide clamps for copper conductors was first put forward, no apprehension was felt as regards excessive wear and tear of the cable material. It was anticipated that, although wear was bound to take place, it would occur to a very limited extent only. By analogy, it was thought that a similar picture should hold good for steel-cored aluminium cable or pure aluminium conductor in a slide clamp made of aluminium. In either case, the conductor material is placed under relatively

identical conditions and, consequently, wear and damage of the material should, essentially, be similar.

To clear this question, there were carried out special experiments at the Tchelyabinsk State Regional Electric Power Station, Russia. Here, under the general direction of Rakusheff<sup>1</sup>, comprehensive tests were made on the requisite types of slide clamp. Three types were tested. The first was of cast iron, having two cast-iron roller bearings, and represented a variety employed for supporting copper conductors with a cross section of 95 mm.<sup>2</sup> on the South Urals network operated at 110 kv., and with an aggregate length of about 286 kiloms. The second type was of the same design, but with aluminium roller bearings. This form was made to support steel-cored aluminium cables with a cross section of 95 mm.<sup>2</sup>. The third type was of a shuttle-like pattern and designed for supporting steel-reinforced aluminium cables of the same diameter (95 mm.<sup>2</sup>); it was wholly of aluminium sheet.

The experiments were, first of all, concerned with the evaluation of wear and tear of the conductor in the course of its movement, and the determination of the effort required to displace the cable, that is, the force necessary to overcome the frictional resistance of the cable upon the inner surface of the clamp.

The body of the clamp was put on a stretched cable, after which the necessary load was applied to the clamp, and the value of the sliding friction estimated. The first to undergo test was a steel-cored aluminium cable in a clamp furnished

with aluminium roller bearings, followed by the comparative tests on the copper conductor in the slide clamp with cast-iron roller bearings. The results of the tests are given in Table 1.

#### Conductor Damage

These clamps were found to cause great damage to the conductors; immediately after the first sliding motion, deep scratches appeared on the cable. The injury to the conductor induced by the roller-bearing clamp was of a character somewhat different from that caused by the shuttle-type clamp. In the first case, it was observed that in the individual strands of the cable deformation took place. Owing to the small contact area between the roller bearing and the cable, separate strands of the latter became flattened and its surface gradually assumed a glossy appearance. The crushed strands spread out, filling the cavities of the cable, so that finally it took on the appearance of a smooth metal rod. These alterations occurred with both the aluminium and copper cables within approximately the same period of time. Figs. 2 and 3 illustrate the appearance of the copper and steel-cored aluminium cables prior to and after the test.

As may be seen, the change in the structure of the cables is so marked that the application of this type of clamp is out of the question. Such a result was obtained after approximately 350 movements of the clamp fitted with aluminium roller bearings. Deformation of the cable begins at once, gradually increases,

Table 1.

| No. | Clamp                                                | Conductor                                                  | Vertical load, kg. | Effort required to move conductor in clamp, kg. | Static coefficient of friction |          |
|-----|------------------------------------------------------|------------------------------------------------------------|--------------------|-------------------------------------------------|--------------------------------|----------|
|     |                                                      |                                                            |                    |                                                 | Partial                        | Average  |
| 1   | Cast-iron clamp having two cast-iron roller bearings | Copper of 95 mm. <sup>2</sup> cross-section                | 100                | 8                                               | 0.080                          | } 0.0757 |
|     |                                                      |                                                            | 200                | 14                                              | 0.070                          |          |
|     |                                                      |                                                            | 300                | 23                                              | 0.077                          |          |
| 2   | Same design furnished with aluminium roller bearings | Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section | 200                | 18                                              | 0.090                          | —        |
| 3   | Aluminium rollerless, shuttle-like pattern           | Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section | 200                | 100                                             | 0.500                          | —        |



Table 2.

| No. | Clamp  | Conductor                                                  | Vertical load, kg. | Effort required to move conductor in clamp, kg. | Static coefficient of friction |         |
|-----|--------|------------------------------------------------------------|--------------------|-------------------------------------------------|--------------------------------|---------|
|     |        |                                                            |                    |                                                 | Partial                        | Average |
| 1   | Oak    | Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section | 100                | 26                                              | 0.260                          | } 0.259 |
|     |        |                                                            | 200                | 51                                              | 0.255                          |         |
|     |        |                                                            | 300                | 79                                              | 0.263                          |         |
| 2   | Spruce | Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section | 100                | 20                                              | 0.200                          | } 0.214 |
|     |        |                                                            | 200                | 44                                              | 0.220                          |         |
|     |        |                                                            | 300                | 67                                              | 0.223                          |         |

and ultimately leads to a complete loss of its original shape and the acquisition of a dull matt appearance. Injuries sustained by the surface of the conductor indicate considerable effect on its mechanical characteristics, in particular, its tensile strength. Thus a cable suspended in roller clamps will, in the course of time, due to constant movement, become notched and constricted, features which inevitably lead to an increased risk of mechanical failure.

#### Need for Adequate Friction

This type of clamp should also be considered as unsuitable for the reason that sliding friction is very slight; therefore, any occurrence of inequality in tension along the conductor (even of so small an order as from 15 to 20 kg.) which may arise in neighbouring spans, instantly results in translational motion of the cable. It is true that the suspension of the cable to the string of insulators, due to the flexibility of the latter, reduces movements of the conductors in the clamps; none the less, injuries sustained by the surface of the cable at the points of its contact with the roller bearings still remain, even in the case of complete immobility of the entire system, as the specific loading at the area of contact is too great.

The roller-less, shuttle-type clamp constructed wholly of aluminium sheet has a distinct advantage over the roller clamp in that it gives a high static friction, i.e., the force, which must be applied before

the cable starts to move, is appreciable, attaining the value of about 100 kg. Thus, casual displacement of the conductor consequent, for example, on unequal loading of the neighbouring spans with ice coatings, are, to a great extent, obviated, but at the same time damage to the cable as a result of movement in the clamp is still very substantial. Frictional resistance is so intense that even a single motion of the conductor in the clamp is enough to pare off shavings from the body of the cable up to 0.5-1.0 mm. thick.

So, in the event of rupture of a conductor in transmission systems erected in slide clamps of the roller-less (or shuttle-like) types, the surface of the cable is bound to be seriously scratched. This is bound to involve an ever-increasing risk of mechanical failure of the line after each breakdown.

The most efficacious way to prevent injury to the surface of the cable in the slide clamp is either to construct the entire clamp of a material which, by virtue of its softness, is incapable of damaging the conductor, or to make from this material only those parts of the clamp which are in direct contact with the cable. For instance, it would be possible to fit in a clamp of the shuttle type a lining of lead; however, such a solution cannot be regarded as suitable for steel-cored aluminium cables on account of the danger of electrolytic corrosion.

On the basis of these considerations it was decided to try wood as a construction material for the slide clamps. With appro-

appropriate dimensions, a clamp made of suitable hardwood (for example, oak) will have quite adequate mechanical strength and at the same time will provide reasonable assurance that the conductor will not, under normal working conditions, be subjected to damage. The only adverse factor in this case (and one very difficult to obviate) is, of course, the combustibility of wood. However, the possibility of ignition of the wooden clamp can be reduced by means of proper design.

A general arrangement of the component parts in the slide clamp constructed of wood is illustrated in Fig. 4.

The possibility of water absorption by the wood and the leaching out of corrosive substances is apparently ignored here. Oak does not seem the happiest choice of hard wood, and beech would appear, on the face of it, more suitable. The use of certain rubber mixes, or of the rubber-like plastics (e.g., polyisobutylene), might also be investigated.

#### Oak Proves Satisfactory

With the oak clamps, after a great number of movements, no traces of injury to the conductor was observed, the only result of a "working" being the formation in the wood of a groove about 3 mm. deep. The spruce clamp was found to be less suitable, as the groove formed in it was deeper, the value of the static friction was from 15 to 20 per cent. smaller than for oak, and the crushing of the outer layers of the spruce was more considerable. In both cases the sliding of the cable in the clamp was across the grain, i.e., at right angles to the direction of the wood fibres.

In order to approach correctly the evaluation of the results obtained, it is essential, first, to consider those forces which act upon the conductor under normal conditions of service. The comparative values of these forces are presented in Table 3.

Making use of the static coefficient of friction, as given in Table 2, it is easy to estimate that the value of the sliding force for a steel-cored aluminium cable of 95 mm.<sup>2</sup> cross-section in the wooden (oak) clamp is about 34.7 kg. with a span of

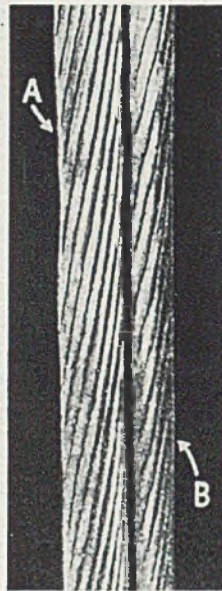


Fig. 3 (above).—Cable lengths as in Fig. 2 after test. Note flattening of the individual strands composing cable, also evidence of kinking and grooving. This damage resulted from sliding of the cable in contact with the metal surface.

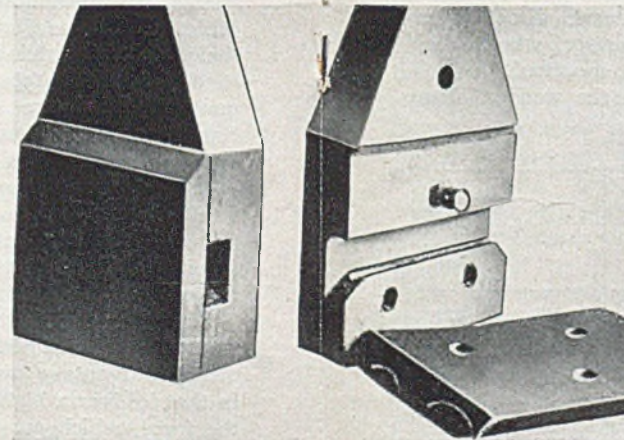


Fig. 4 (right).—View of the wooden slide clamp in the assembled and dismantled state. Note radius given to lower side of slide. Results of tests of clamps of this type in oak and spruce are summarized in Table 3. The soft-wood grooved too readily.

Fig. 5 (below).—Diagram of the composite wood-metal slide clamp: side view and cross-section. The general view shows the component parts together with a superimposed metal plate on which are mounted horn gaps. Side view shows the position of the conductor on the wooden cushion and details of method for fixing structural elements to the metal frame.

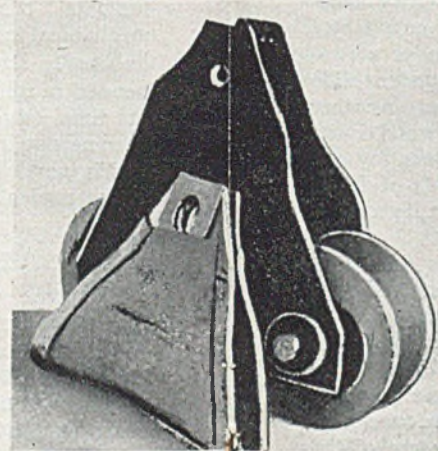
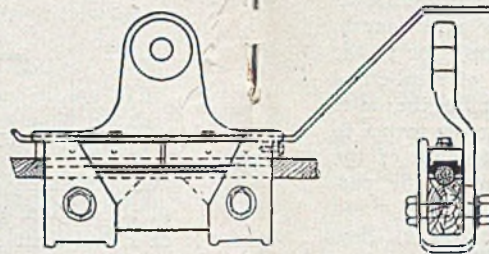


Fig. 2 (above).—Shown here are two lengths of cable, one in copper (A) and one in steel-cored aluminium (B) prior to testing in various types of clamp under operating conditions. Note clear demarcation of component strands.

Fig. 1 (above, left).—View of two types of slide clamp designed for supporting steel-cored aluminium cable. These types were tested by Rakusheff and are described in this account. The aluminium-roller type and the rollerless form in aluminium sheet are shown.

200 metres, and about 43.4 kg. with a span of 250 metres, in the absence of wind and ice coating. In relation to the wind load (free from ice coating) this constitutes in both cases 38.6 per cent., i.e., over one-third of the wind pressure. With a clamp of the roller-bearing type, on the basis of the data of Table 1, we obtain a sliding friction equal to 12.1 kg. with a span of 200 metres and 15 kg. with a span of 250 metres. In other words, in order to move the cable in the clamp, it is necessary to apply a pulling effort, the value of which is, approximately, only 13.3 per cent. of the wind pressure.

#### Surface Damage Avoided

As is seen, the risk of injury to the conductor, in the event of using the roller type of clamp, is much more serious than that from the wooden clamps, in consequence of the considerably greater mobility of the cable supported by roller bearings. This is quite understandable, for the fluctuations in the force of wind, which lead to the variation in the wind loading on the conductor in the two neighbouring spans by 38.6 per cent., are of much less frequent occurrence than those with a change of load of 13 per cent. Thus, with the oak clamps, movements of the cable will take place less frequently than in the case of the roller-bearing clamps. As the wooden unit, as such, is incapable of causing damage to conductors, it follows that reduction of cable movements in the clamp is of interest merely from the viewpoint of a decrease in the wear and tear of the clamp itself, and of avoiding excessive sag, which is observed with the roller-type clamp.

Hitherto, we have dealt with a cable assumed to be free from ice coating. Speaking generally, in the event of ice loading on the conductors, the possibility of their movements in the clamps is greatly diminished. Nevertheless, here again, wooden clamps have an advantage over those of the roller type, for in order that the cable may begin to slide, it is necessary that the weight of ice formed on the conductor in the neighbouring span (which, prior to this, was completely free from the ice load) should be, approxi-

mately, from 45 to 52 kg., depending on the length of the span, as against from 15 to 18 kg. in the case of the roller-bearing clamps.

As the average compressive strength of ice, depending on temperature, is from 10 to 25 kg./cm.<sup>2</sup>, it is obvious that the force required to crush the ice crust formed on the cable will be very small. Indeed, assuming that the coating formed close to the clamp is 20 mm. thick, we will have, for a steel-cored aluminium cable of 95 mm.<sup>2</sup> cross-section, a total ice area equal to about 1.3 cm.<sup>2</sup> The shearing force required to cut this layer will be from 13 to 33 kg., an average of about 19 to 20 kg.

By making use of the foregoing data, it is possible to tabulate general values of the forces required for the sliding motion to occur in the clamp under various conditions of loading, as indicated in Table 4. These values have been computed for a steel-reinforced aluminium cable of 95 mm.<sup>2</sup> cross-section.

Thus, if the conductors be calculated for service at a temperature just under freezing point (say, -5 degrees C.), with attendant wind loads and ice coatings, then, in the event of failure of the cable, it is necessary to reckon the torsional stresses which the line support should withstand at not over 150 kg. On the other hand, in the case of calculations for conductors for duty at lower temperatures (say, -40 degrees C.), but in the absence of wind, it is sufficient to design a support capable of withstanding forces produced by breakdown of the cable as equal to 50 kg.

In either case, with spans of 200 to 250

metres, wind pressure is the decisive factor. The worst conditions for overhead transmission line involve a combination of low temperature, which tends to diminish the sag, and snow or ice coatings, which, in addition to increasing the weight per unit length of the cable and thus augmenting the sag, also increase its overall projected area per unit length; consequently, wind pressures, due to the somewhat larger diameter of steel-cored aluminium cables, may make the total resultant load sufficiently heavy to tax to the limit the mechanical strength of the line support and even imperil the performance of its duties.

#### Improved-wood Clamps

As already mentioned, the easy combustibility of wood is an adverse factor militating against its adoption as a construction material for the wooden slide clamps in transmission lines. Another very serious shortcoming of wood is its liability to decay. Nevertheless, by the application of suitable methods of treatment both these drawbacks can, to a great extent, be mitigated.

Injury to the clamps due to flash-over across the string of insulators may be combated by fitting the usual protective devices, such as horn gaps. As, however, protection against the direct action of arcing should be given not only to the wooden clamp, but to the conductor itself, it follows that the structure of the clamp should possess some metal conducting component, which is directly connected with the conductor, where, then, the horn gaps may be mounted.

This metal part of the wooden clamp

Table 3.

| Conductor                                                     | Span, metres | Weight of conductor in span, kg. | Tension in conductor free from ice-coating, kg. | Wind load with ice-coating, kg. | Ice-loading, kg. | Weight of conductor with ice-coating, kg. |
|---------------------------------------------------------------|--------------|----------------------------------|-------------------------------------------------|---------------------------------|------------------|-------------------------------------------|
| Copper of 95 mm. <sup>2</sup> cross-section ..                | 200          | 169                              | 60.6                                            | 156.3                           | 127.4            | 297                                       |
| Copper of 95 mm. <sup>2</sup> cross-section ..                | 250          | 211                              | 75.8                                            | 195.4                           | 159              | 370                                       |
| Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section .. | 200          | 134                              | 90.3                                            | 186.4                           | 162.6            | 297                                       |
| Steel-cored aluminium of 95 mm. <sup>2</sup> cross-section .. | 250          | 167.5                            | 112.8                                           | 233                             | 203              | 372                                       |

Table 4.

| Span, metres | Nature of force, load                      | Weight of conductor, kg. | Resultant load comprising weight of conductor + wind pressure, kg. | Weight of conductor + ice-coating, kg. | Resultant force comprising weight of conductor + ice-coating + wind-loading, kg. |
|--------------|--------------------------------------------|--------------------------|--------------------------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------|
| 200          | Resultant tension in conductor             | 134                      | 162                                                                | 287                                    | 315                                                                              |
| 200          | Effort required to move conductor in clamp | 34.7                     | 42                                                                 | 77                                     | $91 + 20^* = 111$                                                                |
| 250          | Resultant tension in conductor             | 167.5                    | 202                                                                | 373                                    | 407.5                                                                            |
| 250          | Effort required to move conductor in clamp | 43.5                     | 52.4                                                               | 96.5                                   | $111 + 20^* = 131$                                                               |

N.B.— $20^*$  is average shearing force, in kg., required to cut the layer of ice.

should not carry any of the conductor's load, the whole weight of which must be supported by the wooden body of the clamp. Fig. 5 illustrates the construction of a mixed wood-metal slide clamp furnished with a top metal plate which carries the horn gaps and ensures the by-pass flow of current away from the wooden parts, thus protecting the wooden body of the unit from the ill-effects of arcing.

#### Design of Wood-Metal Clamps

In the construction of slide clamps of this type care should be taken to prevent the formation of closed electro-conductive contours, which are insulated by means of interposed wooden components from the horns of the arc-suppressing device, as otherwise, in such a case, there is obtained a short-circuited transformer causing an extra loss of energy in the line, heating of the short-circuited parts of the clamp, and an increased displacement of phases.

In the composite clamp, which is housed in a metal frame, as depicted in Fig. 5, all the tensile stresses are carried by the metal components, whilst the wooden part serves only as a compression member acting as a cushion for the suspended cable.

To prevent excessive wear of the clamps, they must be designed in such a manner that pressure exerted by the weight of the cable on the wooden components should not exceed, for oak, 10-15 kg. per square centimetre of the pro-

jected area of the conductor upon the plane of the clamp.

The combustibility of the wooden structure of the clamp can, to a considerable degree, be averted by selecting a hard, dense variety of wood, which is difficult to ignite, for example, oak. Generally speaking, actual burning of the clamps containing wooden elements could hardly be expected under the usual conditions of service in overhead transmission lines. What may occur, however, is superficial charring, which, fortunately, does not affect the mechanical strength of the unit, for, as is known, under the action of a flame, wood loses its strength far more slowly than metal.

The coating of wood with various fire-proof media and paints, or its treatment with special anti-flame compounds cannot be recommended, as most of these compositions are not indifferent to aluminium. One of the most effective means for the protection of the wooden parts of the clamp is its impregnation with a compound chemically inert to the conductor material, such as, for instance, resins that are perfectly neutral to light metal; alternatively, the wooden elements may be coated with a thin, tough layer of aluminium by means of the spray gun. Metallized wood will be protected not merely from ignition, but largely, also, from decay.

From a general list of chemical substances used for preservative treatment of wood, there should be excluded those compounds which contain certain halo-

gen compounds (e.g., chlorides) on account of their deleterious action on aluminium. For the same reason, the oxides and other compounds of heavy metals should also be rejected; chromium compounds may possibly be admitted for use here, however. A good all-round method consists in surface treatment, or, better still, in impregnating with phenolics or other type of synthetic resins, for example, by the process developed by the author.<sup>2</sup>

#### Treatment Media to Avoid

Painting of the wooden elements of slide clamps with boiled linseed oil, or their impregnation with transformer oil, must be avoided—the former on account of the inadequacy of the results obtained, and the latter in consequence of the almost two-fold reduction of the friction coefficient of the conductor in the clamp, and, moreover, owing to the increased fire hazard of a petroleum-impregnated wood.

Of the methods now employed with a view to reducing the torsional forces, to which the line support is subjected at the moment of failure of a conductor, the application of twin brackets, combined with the securing of the cables in clamps of a fixed type, are found to give satisfactory results. In this case, provided that the operation of erecting the cable in the clamp be carried out in a correct manner, there will be no sliding of the conductor at the points of its attachment, and, consequently, complete immunity of the cable to damage. However, the degree to which torsional stresses in the supports are lowered with the aid of this contrivance is relatively small, being approximately 15 to 20 per cent. The other variety of clamp is of a rather controversial nature. This is of an ejector type, designed on the principle that, in the event of a certain definite load occurring along the conductor, the latter is automatically disengaged and is allowed to drop to the ground. In this case there is no guarantee against injury to the cable by its fall from a height of 9-10 metres

and through dragging on the ground due to the difference of tension in the neighbouring spans; hence the application of this type of clamp to steel-reinforced aluminium cables is conditioned by special factors. As a rule, when erection work has to be done on hard, rocky ground, where the risk of injury to the cable by its falling and dragging on the earth is very great, the adoption of the ejector clamp for supporting steel-cored aluminium cables is hardly justifiable. On the contrary, in flat, grass-covered localities this type may be found useful.

Suspension of the conductors in slide and semi-slide (disengaging) clamps of the usual construction as at present employed, although capable of safeguarding the line support against excessive torsional stresses at the moment of mechanical failure of the conductor, attains this advantage by the sacrifice of the cable surface, which may suffer severe injury, due to sliding friction. Bearing in mind how carefully the unwinding of a steel-cored aluminium cable from the drum and its suspension and attachment to the line support have to be carried out, all with the sole aim of avoiding surface damage, it is clear that deliberate wear and tear, inevitable with metal slide clamps, render these devices almost useless.

#### Value of Wood Demonstrated

As may readily be seen, the only effective method capable of protecting an aluminium conductor from injury at points of support is the application of the wooden or composite, wood-metal slide clamps. Clamps of this type definitely offer a highly favourable performance, both in respect of the value of sliding friction for the cable, as well as wear of the material of the clamps themselves.

*(To be continued)*

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- (1) Rakusheff; *Electricity*, No. 14, 1932. *Jl. Electrical Industry*, X, 601, 1942. (2) Brajnukoff; *Chemical Products*, No. 3, 71, 1939.

# Light Alloys in Rectifiers, Photocells and Condensers

*An Exhaustive Discussion is Presented on the Theory, Practice, and Operation of the Electrolytic Condenser. In Particular, the Properties of the Aluminium-oxide Film are Considered. (Continued from "Light Metals," 1944/7/566).*

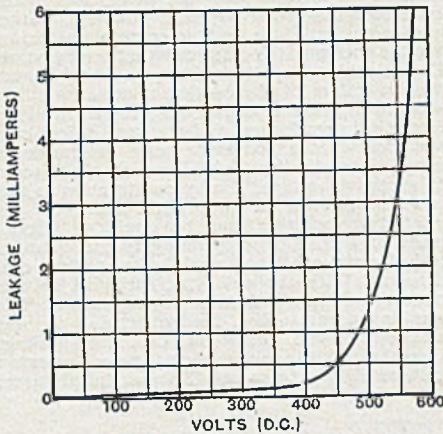


Fig. 103.—Voltage characteristic of electrolytic condenser.

IN the opening section of this discussion on electrolytic condensers presented on pages 565 and 566 of "Light Metals" for December, 1944, the basic structural principles and applications of various types of condenser were briefly outlined. The account on the pages referred to concluded with a reference to the forming process and to the electrolyte designated in Fig. 102 on page 565 by the letters E.E. This electrolyte, strictly speaking, is the second electrode of the combination, and the so-called second electrode ( $M_1$ ,  $M_2$ ) is really the convenient practical way of securing a manipulable contact. The electrolyte itself is a conducting material in the form of a liquid, a paste, or a solid. This electrolyte is not necessarily the actual one in which the first electrode is "formed," but contains similar ingredients and is, therefore, of like nature. It has to fulfil functions other than those of contact. Thus, the dielectric film as first produced is porous, and in the condenser permits current to pass. The electrolyte, therefore, has to serve the purpose of quickly repairing the film or of providing a new one, immediately an electrical load is placed on the condenser.

In paper and mica condensers, the particular metal employed for the electrodes is of secondary importance. In electrolytic condensers, it is of primary importance, because it must permit the formation of a suitable film, and the maintenance of this film during operation. Aluminium has unique properties in this direction.

The dielectric film produced on aluminium by the electrochemical process of forming, which is an oxidation process, consists in part of aluminium oxide. The dielectric strength of the film and the voltage that it will withstand in

service without rupture are functions of thickness and physical structure. These factors are determined by the nature of the chemical solution from which it is produced, and the process conditions (temperature, voltage, time, etc.) employed.

In the completed condenser, the filmed electrode, known as the anode, is always the positive pole of the condenser. Coursey points out that as electrolytic condensers are polarized, they are, generally speaking, suitable for use only in circuits in which they are subjected to unidirectional voltages, in order that the current through them is not reversed. Thus the elec-

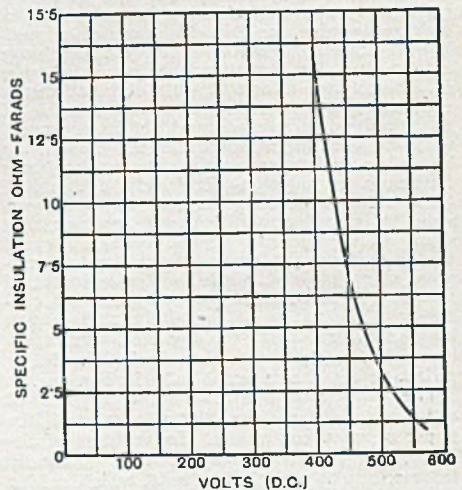


Fig. 104.—"Insulation resistance" of electrolytic condenser.

trode M<sub>1</sub> is always positive and M<sub>2</sub> always negative. If the reverse connections be made, the dielectric film will become destroyed by dissolution in the electrolyte, gas will be evolved, and the condenser may burst.

Again, in contrast with the other types, the electrolytics are characterized by a relatively high-leakage current which continuously passes under the influence of an applied voltage when they are in use. Although this leakage current is generally considered to be very small, it is largely compared with the minute leakage cur-

with this, as the applied voltage is increased on an electrolytic condenser, it can be seen from Fig. 103 that the leakage current gradually increases at first, and then very rapidly increases as shown by the sudden turn in the curve. Thus, an indication of approach to the limiting safe voltage is given. The reason for the change is largely a thermal one, viz., energy loss in the condenser dissipated as heat, becoming larger and larger, and the leakage current becoming further increased by the increased temperature. Conditions such as these are very unstable and, finally, failure of the condenser occurs.

Some measure of self-healing is exhibited by electrolytic condensers and the mechanical construction of the condenser may determine in some degree the form of failure when subjected to excessive voltage. Under construction in this sense is inferred the type with respect to the electrolyte, whether this be liquid, a viscous paste or a solid, corresponding to the commercial descriptions wet, semi-dry and dry condensers. With the wet type, excessive voltage punctures the dielectric film and audible sparking occurs under the liquid, due to heat and electrolytic action of the large leakage current. With the semi-dry type, excessive voltage ultimately causes the mechanical spacer

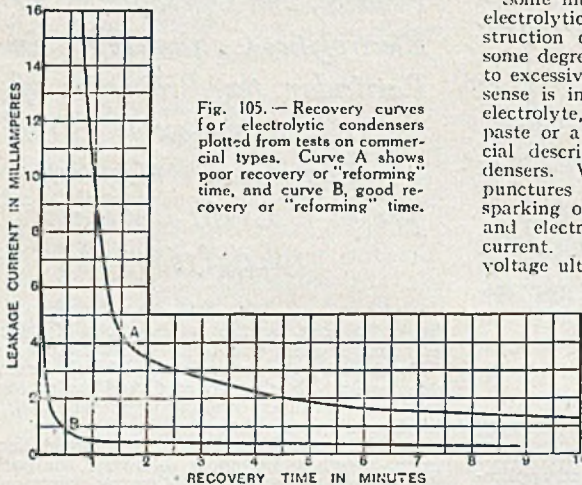
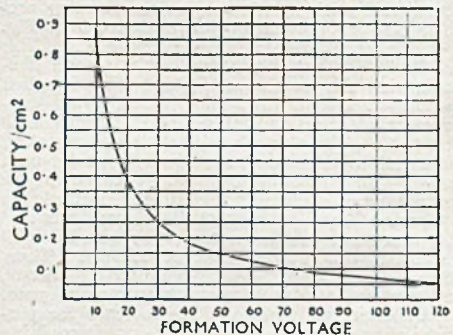


Fig. 105.—Recovery curves for electrolytic condensers plotted from tests on commercial types. Curve A shows poor recovery or "reforming" time, and curve B, good recovery or "reforming" time.

Fig. 106 (Below).—Variation of capacity/cm<sup>2</sup> with formation voltage. (After Bairsto and Mercer.)



rent through the insulation of paper or mica condensers.

In the usually accepted sense of the expression "insulation resistance," it should be noted that electrolytic condensers have no insulation resistance. The dielectric film has, of course, a resistance value, and in the case of a well-known brand of 450-volt electrolytic condenser of capacity of 8 microfarads, it is of the order of 2 megohms. Coursey points out that this is equivalent to an insulation resistance value of 16 megohm microfarads, which is compared with a good paper condenser for which the insulation resistance would amount to some thousands of megohm-microfarads, a figure of quite different order. Again, the resistance value of the electrolytic is not constant, but varies widely with the applied voltage, because the leakage current is very minute for low voltages, rising rapidly as the voltage is increased beyond the rated value for the particular condenser. The nature of this variation is shown by the typical curve in Fig. 103, whilst the corresponding values for the so-called insulation resistance are shown graphically in Fig. 104.

The curves demonstrate another point of difference between the electrolytics and the paper or mica condensers. In the case of the latter, the applied voltage can be gradually increased up to a critical value at which sudden puncture or rupture of the condenser occurs; this value is the breakdown voltage. In contrast

of paper or cloth, which is used to separate the metal electrodes, to char by excessive local heating. The film may also puncture, and then gas is liberated, which may mechanically separate the plates, due to the suddenness of its liberation; this may prevent a short circuit from forming. Both with the wet and semi-dry types, a momentary overload will result in resealing, but a maintained overload will cause enough overheating to destroy the condenser. With the dry type, excessive voltage usually produces a sudden puncture and complete failure as with paper and mica condensers.

Coursey points out that in radio-receiver circuits, when excessive voltage on the condenser causes higher leakage current, the latter on the rectifier tends to keep the voltage down, so there is some measure of protection, but, nevertheless, a sustained overload will still tend to cause thermal damage to the electrolytic condenser.

Electrolytics are operated much nearer to their maximum safe voltages than is possible with the paper and mica types. A margin of safety between operating voltage and breakdown voltage in the ratio of 1 to 5 or 1 to 6 is usual for the paper and mica condensers, whereas a ratio of 1 to 1.2 or 1 to 1.5 is the normal for

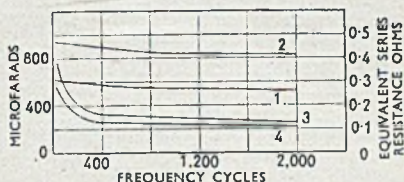


Fig. 109.—Capacity-frequency and resistance-frequency change of aluminium condenser formed at 100V. and operated at 65V. d.c. (After Siegmund.)

which for dry types may be from 5 to 10 per cent., but for wet types may reach values as high as 25 to 30 per cent. These values set a limit to the amount of maximum permissible ripple voltage that can be tolerated superimposed upon the normal d.c. voltage of the condenser without causing deterioration from overheating.

Intimately connected with the power factor is the effective value of the capacity of the condenser and the manner in which it changes with variations in the frequency of the ripple voltage. The series resistance of the electrolyte reduces the effective capacity of the condenser to alternating current. Further, when these condensers are used for smoothing rectified alternating currents, the effective a.c. capacity is the only one with which the user is really concerned. This value in microfarads is generally measured and quoted at a frequency of 50 cycles. With condensers having a small power factor, the change between 50 cycles and 100 cycles, which is the normal ripple frequency for double wave rectification, can be neglected. For high power factor condensers, this is not so, and the difference becomes important.

The degree of stability of the dielectric itself (as compared with paper and mica) is another peculiarity of electrolytic condensers. With paper and mica condensers, no change should occur in the dielectric of properly made components when they stand idle, unused, and with no applied voltage. With electrolytics, some changes may occur under such conditions,

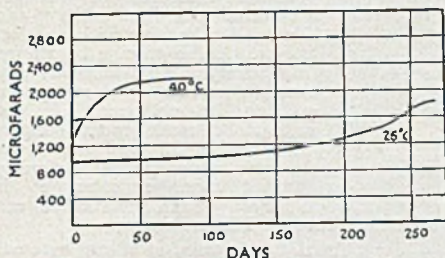


Fig. 107 (above).—Capacity-time change of electrolytic condensers operated at half formation voltage (both with ammonium-borate solution of same conductivity). Different temperatures. (After Siegmund.)

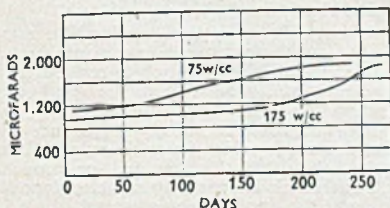


Fig. 108.—Capacity-time change of electrolytic condensers operated at half formation voltage, both at room temperature; ammonium-borate solutions of different conductivities. (After Siegmund.)

electrolytic condensers. It is the physical and chemical constructional nature of the two types that accounts for this discrepancy and makes the close margin for electrolytics a safe one. Nevertheless, the small margin of safety must be borne in mind when fixing other portions of the circuit in which used.

Power factor is another discriminating feature of electrolytic condensers. The electrolyte is not a perfect conductor and possesses a definite resistance value against the current flowing through it. This resistance is considerably less with semi-dry or dry electrolytics, because the electrodes can be spaced closer together, thus reducing the resistance through the path of separation.

Alternating or ripple current through the condenser is accompanied by the development of heat and the corresponding energy loss. This is expressed numerically as a power factor value,

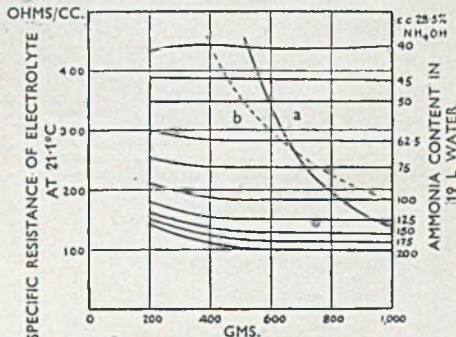


Fig. 110.—Specific resistance of ammonium-borate solution (after Siegmund). Boric acid content is given in grams in 19 litres of water: Curve A, neutral solution, pH equals 7.0; curve B, constant proportion of boric acid and ammonium.



although research and development is always towards the elimination of such changes. When a d.c. voltage is applied to an electrolytic condenser after it has laid idle, there is a sudden rush of current initially, and this only gradually falls to the normal leakage current value. This compares to the so-called "absorption" characteristic of paper and mica condensers, although it is much more pronounced. With high-grade electrolytics, this abnormal leakage current is, for all practical purposes, over in a fraction of a minute, although earlier commercial condensers showed it persisting for longer periods. Typical curves are shown in Fig. 105.

Coursey summarizes the salient features and merits in usage. The advantage is small size for a given microlard capacity, and, in consequence, lower cost. Disadvantages are centred in their peculiar properties, which demand special consideration in practical applications. The disadvantages apply limitations in their application to the smoothing of d.c. circuits having a comparatively small a.c. ripple element. He points out that electrolytic condenser design must be a compromise between the effects of conflicting properties and requirements, and that probably the semi-dry types offer the best solution, compromising between the advantages and disadvantages of the two extremes of wet and dry.

An informative contribution to the technical literature on the subject was an article by Rollo Appleyard, entitled: "The Aluminium Electrolytic Condenser" in "The Philosophical Magazine," Vol. 8, 1929, and reprinted by R. E. W. Maddison in "Electrical Communication," 1931. This paper dealt with anodic polarization, the theories of electrolytic valve action, anodic-film

formation, thickness of the film, its electrical strength and electrostatic capacity, the electrodes and electrolyte for electrolytic condensers, the influence of impurity, condenser properties and other electrical characteristics. As this publication is regarded as a fundamental reference document, the following abstracts and illustrations are taken from it.

#### Anodic Polarization

Between the electrodes of an electrolytic cell there is a natural potential difference or voltage; the same can be said of an electrode in contact with an electrolyte. If the voltage be altered from its equilibrium value by any cause, electrodes or electrode are said to be polarized. If the voltage be made more positive than the equilibrium value, the electrode is *anodically polarized* and, if more negative, it is *cathodically polarized*. Such polarization can result from several different causes:—

(a) From the impressing of an external voltage on the electrodes of the cell.

(b) From changes in concentration of the electrolyte in the cell.

(c) From interference with the normal electrode reaction, as, for example, by the production of a non-conducting film upon that electrode.

The formation of a non-conducting film anodically upon an electrode is an important phenomenon in the aluminium electrolyte condenser, and the physics and chemistry of the film and its formation are interesting.

A metal dissolves anodically to produce metal ions which are capable of combining with ions in the electrolyte. If this combination produce a substance which is sparingly soluble, deposition of it upon the anodic electrode may result, and this will hinder further dissolution of the metal. The effective area of the electrode in the electrolyte thereby becomes reduced and, in consequence, the current density upon the areas not

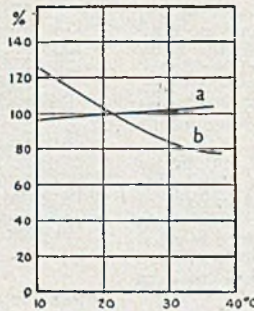


Fig. 111.—Percentage variation (%) with temperature, of capacity and equivalent series resistance of 48V condenser at 1,000 cycles (after Siegmund): A, capacity curve; B, equivalent series-resistance curve.

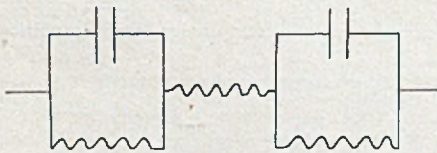


Fig. 112 (above).—De Bruyne and Sanderson. Equivalent circuit: two similar electrolytic condenser plates. Fig. 113 (below).—De Bruyne and Sanderson. Equivalent circuit: two similar plates of equal area.

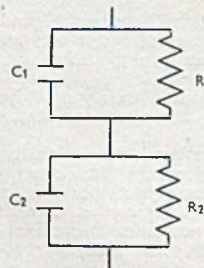
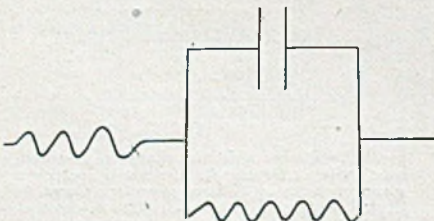


Fig. 114.—Equivalent circuit of an electrolytic condenser.

affected becomes increased. An increased polarization is then necessary in order to maintain a given current and, as a result, the electrode reaction may become modified. If the electrode become completely covered by such a film, exceedingly high polarizations may occur.



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Obviously, the physical properties of the electrode film will vary with all the circumstances of its formation. Among the properties referred to are its thickness, porosity, and electrical conductivity or resistance. The circumstances mentioned will include the composition of the electrode and the physical nature of its surface, and composition of the electrolyte, temperature and electrical conditions. It is the formation of films of poor electrical conductance upon metal anodes which makes the commercial production of electrolytic condensers and rectifiers feasible, because some such films enable high voltages to be maintained between the electrode and the electrolyte, they prevent the discharge of anions or the discharge of any appreciable current, and they remain relatively stable when the anode film is made a cathode.

Unidirectional current conductance is the characteristic property of the anode film upon which its rectifying property is dependent. Thus, when the electrode is made positive, the film forms and then the current passing is very small; on reversing the polarity, current is conducted. Therefore, the film acts as a valve, and under appropriate conditions of arrangements of electrodes possessing these films, the rectification of alternating current becomes possible. Again, the films exhibit a very high electrostatic capacity, and it is this property that is the basis of their use in electrostatic condensers.

There is no reason why all metals should not exhibit these electrical characteristics if suitable conditions can be established for film formation, and it has been established that most metals do behave in this way. At the same time, only two have found commercial exploitation in this direction. These are aluminium and tantalum. Both of these have been used commercially for rectifiers, but for electrostatic condensers, aluminium alone has been utilized.

#### Theories of Electrolytic Valve Action

As always in such circumstances, a number of theories have been gradually built up as knowledge extends and are formulated to explain both the unidirectional current-flow characteristics and the dielectric properties of the anode films. They are grouped into two classes and referred to as the gas-film theory and the solid-film theory respectively, dependent upon whether the film is considered to be gaseous or solid. It is pointed out that, although a visible oxide film is present on a formed anode such as aluminium, it is considered certain that this visible layer is not the active one, but that another inner film is formed which is responsible for the electrical behaviour of the electrode.

#### The Gas-film Theory

The high resistance of the aluminium anode film is attributed by K. E. Guthe ("Phys. Rev." 15, p. 327, 1902) to the presence of a thin film of gaseous oxygen which covers the anode and prevents the passage of negative ions from the electrolyte to the electrode. He likens the film produced on the anode surface to a semi-permeable membrane which allows only certain ions to pass through it and become discharged. In the original paper the well-known copper ferrocyanide semi-permeable membrane is compared with the aluminium anode shown to be similar in behaviour. Thus, it was shown that

with copper and platinum electrodes in an electrolyte, the electrodes being separated by the copper-ferrocyanide membrane, a high resistance exists when current is passed in the direction from copper to platinum, whereas in the opposite direction the resistance is very low.

A. Günthe-Schulze ("Ann. Phys." 4, 21, p. 929, 1906, and 4, 22, p. 543, 1907. Also "Elektrische Gleichrichter und Ventile," J. Kösel and F. Lustet, München, 1924) is also an outstanding exponent of the gas-film theory. He considers that, during the formation period, two films are produced simultaneously, these comprising an inactive solid oxide film and an active gas film. This solid oxide film does not contribute either to the rectifying properties or the condenser characteristics of the electrode, but its function is to hold the oxygen gas film in position. It is the oxygen gas film that has the dielectric qualities. The pores of the oxide layer which are

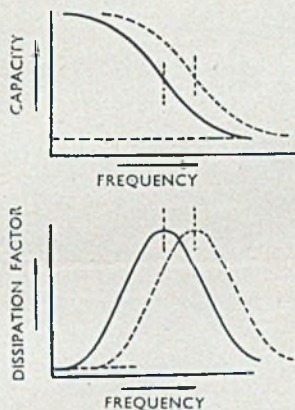


Fig. 115 (uppermost).—Frequency characteristics, for capacity, of the equivalent circuit shown in Fig. 114, for different values of  $R_2$ . Fig. 116 (lower illustration).—Frequency characteristics, for dissipation factor, of the equivalent circuit shown in Fig. 114, for different values of  $R_2$ .

not occupied by gas are filled with electrolyte, and it is considered that electrons from the metal electrode can cross the gas film, whereas ions from the electrolyte are unable to pass through it.

A. H. Taylor ("Ann. Phys.," 4, 30, p. 987, 1909) extends the Günthe-Schulze hypothesis and concludes that the gas film is held between a layer of aluminium hydroxide and the aluminium electrode, and that the gas in contact with the aluminium surface combines partially with it to yield a thin film of aluminium oxide.

#### The Solid-film Theory

Numerous other workers ascribe the rectifying and condenser properties of the aluminium anode to the presence of a solid film which may act as one of the following:—

- (a) A Wehnelt interrupter;
- (b) an ohmic resistance;
- (c) a true dielectric;
- (d) a semi-permeable membrane.

For details, the original references can be consulted; these are as follows:—

M. Jacob, "Sammlung Elektrot. Vorträge," 9, p. 1, 1906.

W. Mitkiewicz, "Phys. Z.," 2, p. 747, 1907.

W. R. Mott, "Electroch. Ind.," 2, p. 352, 1904.

W. W. Taylor and T. K. H. Inglis, "Phil. Mag.," 6, 5, p. 301, 1903.

C. I. Zimmerman, "Trans. Amer. Electroch. Soc.," 5, p. 147, 1904, and 7, p. 309, 1905.

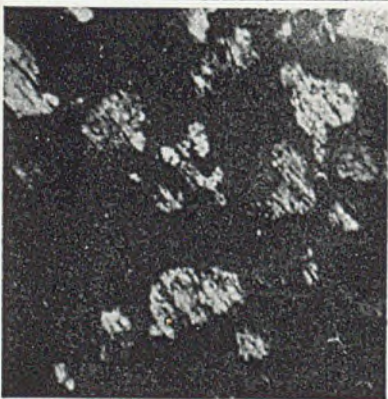
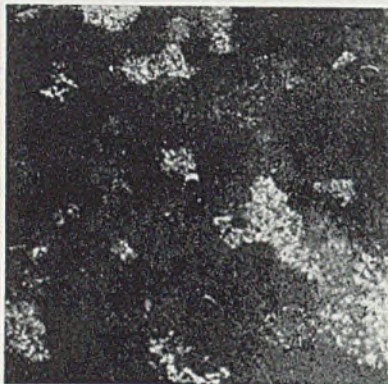


Fig. 117 (lower illustration).—Photomicrograph ( $\times 35$ ) of translucent oxide film placed between crossed Polaroid discs. (Uppermost illustration) Photomicrograph ( $\times 70$ ) of etched surface of aluminium foil by reflected light.

J. Slepian ("Trans. Amer. Electroch. Soc.," 54, p. 201, 1928) applies the principle of thermionic rectification to elucidate the operation of thin films on the solid film theory basis for electrolytic and other rectifiers. He considers that the gas film theory of rectification is untenable for the following reasons:—First, a gas film has a low dielectric constant, a little over unity, and, therefore, it is difficult to account for a sufficient lowering of the work function to

permit electron emission from a metal surface at ordinary temperatures. Secondly, the work function for the escape of ions from an aqueous solution should be less in the case of electrons escaping from a metal surface. Thirdly, electronic conduction may be imparted to the electrolyte without in any way destroying the rectifying properties of the film. He, therefore, prefers to attribute the behaviour of a valve anode to the solid film that covers the surface of the electrode. For aluminium, he thinks the film consists of a transition or dehydration product of aluminium hydroxide that is produced during the process of forming. He considers that this film possesses insulating properties because of an almost complete lack of free electrons, exactly as in the case of a vacuum. Electron emission from the metal electrode into the insulating film is then controlled by a work function just as is the case from a metal to a vacuum. Further, as a result of the definite time period which is required for electrons to traverse the film from one electrode to the other, space-charge effects arise and these reduce the current flow to a very small value.

The dielectric constant of the film also influences the work function. The extent of the attraction exerted by the dielectric on the electrons escaping from the metal surface depends upon whether the work function forces are operative within or without the dielectric layer. Assuming a dielectric constant of 13, the work function may be reduced to from  $1/13$  to  $1/7$  of its value for vacuum. As electron emission is approximately proportional to the work function, it follows that it is possible for electron emission to occur at ordinary temperatures into a film of dielectric constant of about 13, and that the electric field necessary to enable electrons to overcome the work function will be proportionally reduced.

This has assumed that the dielectric film is uniformly distributed over the surface of the electrode. The forces of the work function are operative through a distance of about  $10^{-8}$  cms.; this is of the order of atomic dimensions, and would mean that the film is discontinuous. It is possible that where the film is built up on the electrode itself, the work function is suppressed at some areas and operative at others and electrons will pass from the metal to the film only at certain discreet points. The combination of a favourably polarizable junction with one that is non-polarizable, gives an asymmetric arrangement which will give the unidirectional current flow of characteristics upon which the production of electrolytic rectifiers and condensers is dependent.

F. M. Gentry ("Science," 66, p. 284, 1927; "Trans. Amer. Electroch. Soc.," 54, p. 232, 1928; H. O. Siegmund, "Trans. Amer. Electroch. Soc.," 53, p. 203, 1928, and "B.S.T.J.," 8, p. 41, 1929) mathematically established that the electronic conduction in unidirectional current non-metallic films follows essentially the same law as for electronic conduction in vacuum. Calculated and observed values for current passed at various voltages by the film of an aluminium electrolytic condenser agreed satisfactorily.

In support of the solid-layer theory, it is recorded that a condenser having calcium fluoride as solid dielectric, and which is analogous to the electrolytic type, has been prepared

(N. V. Philips, Gloelampenfabrieken, E.P. 184, 436), and is constructed as follows:—A metal filament covered with a layer of this salt is fused into a glass vessel, the walls of which are covered locally with a metal layer. The vessel is exhausted to a high vacuum. The filament is then heated first to vaporize the salt layer and, finally, to a higher temperature in order to volatilize it and deposit it on the salt layer. The dielectric is 100 to 150 molecules thick and has a breakdown voltage of about  $10^7$  volts per cm.

W. W. Taylor and T. K. H. Inglis ("Phil. Mag.," 6, p. 301, 1903) reproduced the essential characteristics of an aluminium anode of the electrolytic condenser by depositing a film of aluminium hydroxide upon a platinum anode. The film behaves as a semi-permeable membrane in permitting the diffusion of certain salts, but not others. A. L. Fitch ("Phys. Rev.," 2, 9, p. 15, 1917) developed a theory based on a double dielectric consisting of a gas and solid layer to account for the behaviour of the aluminium anode.

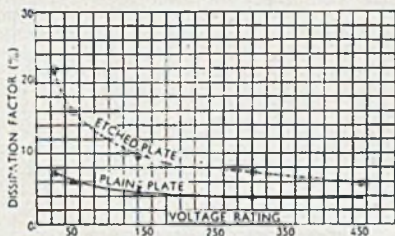


Fig. 118.—Variation of power factor (at 25°C. and 120 cycles with voltage rating, for plain (lower curve), and etched (upper curve), plate dry electrolytic condensers.

*Formation of the Anode Film*

When one of the so-called valve metals (e.g., aluminium or tantalum) is made the anode in an electrolyte, the voltage required to maintain a given current density *increases* almost proportionally with the time of the closed circuit. At a certain voltage, partial breakdown, and at a still higher voltage, complete breakdown, of the film occurs. This period of polarization is known as the "formation period."

The formation of the dielectric film can be achieved with direct or alternating current. On aluminium, the film, as it first appears, is transparent and colourless, but as it builds-up in thickness, the interference colours become visible and, after usage, the increased thickness causes the film to be greyish. The current density at any given voltage and frequency influences the time of formation. The greater the current density (or the smaller the surface area) the quicker is the formation. H. D. Holler and J. P. Schrodt (U.S. Bureau of Standards, Tech. Paper No. 265, 1924) give the following figures:—

- (a) 25 volts d.c. to an area of 1 sq. cm. of aluminium anode gave almost instant formation, current being reduced to nearly zero in 3 secs.
- (b) 120 volts d.c. to an area of 300 sq. cm. caused such slow formation that several

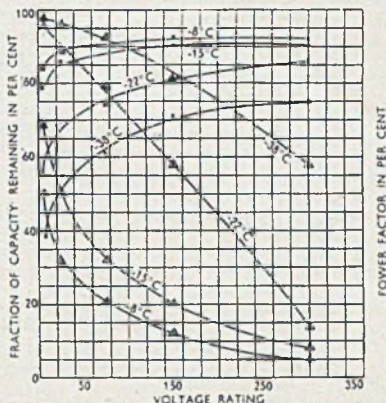


Fig. 119.—Change with temperature of power factor (triangular plotting points) and capacity (x plotting points), of dry electrolytic condensers, as functions of voltage rating.

hours were necessary to yield complete formation.

(c) Using a.c., but otherwise similar conditions, formation periods were five times as long.

(d) Electrolyte composition and temperature influenced the formation times.

H. Sutton and J. W. W. Willstrop (J. Inst. Metals, 38, p. 259, 1927) showed that upon heating anodically treated aluminium in vacuo, the amount of gas evolved was negligible and concluded that the film consists of aluminium oxide and not hydroxide, which is interesting in relation to Slepian's views given before.

*Thickness of the Active Layer*

It has already been indicated that a distinction has to be drawn between the visible oxide layer and the inner active layer. The thickness of the

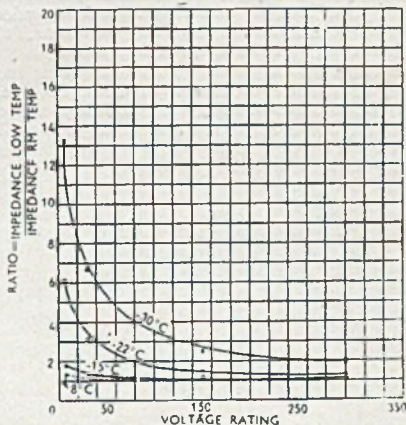


Fig. 120.—Change with temperature of the ratio of low temperature to room temperature (25°C.) impedance at 160 cycles, of dry electrolytic condensers as a function of voltage rating.

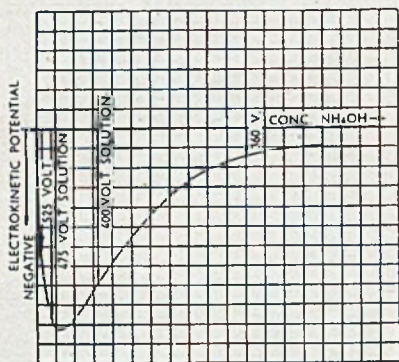


Fig. 121.—Change of relative zeta potential of  $\text{Al}_2\text{O}_3$  in boric acid solutions as a function of the concentration of ammonium borate.

latter has been determined by the following methods:—

- Measurements of electrostatic capacity, assuming a dielectric constant of unity.
- Estimation from interference colours.
- Determination by chemical analysis.

The last two methods, of course, assume that the entire thickness of film is effective as dielectric. A summary of values is given by G. E. Baird and R. Mercer in "Trans. Far. Soc.," 7, p. 1, 1911. Capacity measurements yield results of different order from those of other methods of determination. Thus they give figures of the order of  $10^{-6}$  cm. for aluminium formed at 100 volts, whereas other methods give values from 20 to  $100 \times 10^{-6}$  cm. The capacity measurements are practically independent of the electrolyte, and these results suggest that the anodic film produced on aluminium does, in fact, consist of two layers. Günthe-Schulze (loc. cit.) asserts that the thickness of the active layer is dependent upon the metal employed and the applied voltage, and that it is independent of the electrolyte for aqueous solutions, the temperature, and the mode of formation.

In Table 19 are given relative thickness data (ratio of absolute thickness to dielectric thickness) for the active layer on aluminium and on tantalum formed at various voltages on the

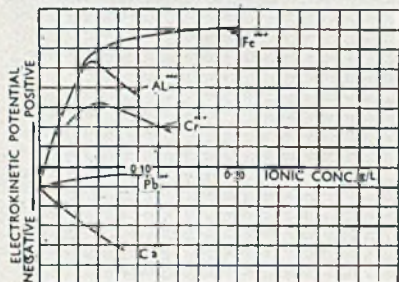


Fig. 122.—Effect of addition of various positive ions on the relative zeta potential of  $\text{Al}_2\text{O}_3$  in boric acid solutions.

assumption that the dielectric constant is unity. Capacity measurements of thickness are affected by frequency, but at a given value for the latter, the electrostatic capacity is a function of the applied voltage. This capacity is taken as a measure of the thickness of the active layer. The tabulated values show the increase in thickness with increasing voltage and the greater thickness on aluminium than on tantalum.

#### Resistance of the Active Layer

Evidence mostly points to the resistance of the active layer being purely ohmic in nature, although it has been attributed to a counter e.m.f. A Günthe-Schulze ("Phys. Z.," 22, p. 146, 1921) showed the resistance is a function of the thickness of the layer at any particular applied voltage, i.e., it is dependent also upon voltage.

Table 20 gives data appertaining to tantalum formed at 100 volts d.c. at 20 degrees C. in 0.05N potassium nitrate solution. Tantalum was employed in preference to aluminium because

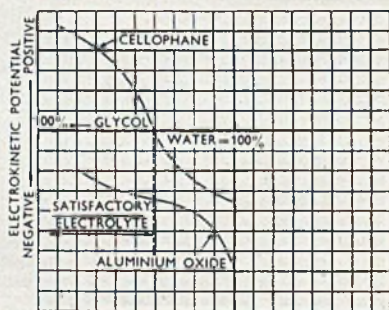


Fig. 123.—The relative zeta potential of "Cellophane" and  $\text{Al}_2\text{O}_3$  in glycol/water mixtures containing 10 gms. borax per litre.

results are not obscured by the incomplete insolubility of this metal in the electrolyte as they are with aluminium. It can be seen that the current decreases more rapidly than the thickness of the active layer increases, so that the resistance of the active layer at constant voltage increases very rapidly with decreasing forming current.

Table 21 gives further resistance values over a range of voltages, first, for aluminium formed in ammonium borate solution at 350 volts d.c. and, secondly, for tantalum in 0.05N borax solution formed for one day at 200 volts d.c.

The data given in Tables 20 and 21 for resistance of the active layer show that the discharge of an electrolyte condenser takes place more slowly than it would if it possessed a constant ohmic resistance. The time of discharge is greater the longer the period of charging, because the ratio  $e/i$  is greater, although the corresponding change in electrostatic capacity and thickness of active film is much less. The figures in Table 21 should be taken as indicating only the general trend of the voltage resistance characteristic because the individual values given have to allow an interval to elapse between readings, and are also dependent upon whether the voltage is increasing or decreasing.

W. R. Mott gives the specific resistance of the film formed on aluminium in phosphate and sulphate solutions as  $10 \times 10^{10}$  and  $0.8 \times 10^{10}$  ohms./c.c. respectively at 25 degrees C., the resistance decreasing as a logarithmic function of temperature ("Electroch. Ind.," 2, p. 352, 1904). W. E. Meserve computes the resistance of the solid layer to be  $3.4 \times 10^{12}$  ohms./c.c. on the assumption that it is aluminium oxide,  $\text{Al}_2\text{O}_3$  ("Phys. Rev.," 30, p. 215, 1927).

The values in Table 22 are due to H. O. Siegmunde for aluminium formed in ammonium borate solution at 350 volts d.c., and show current-voltage characteristics. The d.c. leakage current value of an electrolytic condenser at constant voltage decreases with time. At a potential less than the forming voltage, the d.c. current leakage through the film is about one micro-ampere per sq. cm. Schulze, in his paper, quoted 0.15 micro-ampere per sq. cm. for aluminium formed at 110 volts in ammonium borate solution. The leakage current greatly increases when corrosion occurs at the electrodes and may rise to 20 or 30 fold. Corrosion product, if accumulating between the electrodes, may even deform the plates, cause them to touch and produce a short circuit. The result of this may well be the total destruction of the condenser and of components associated with it in the circuit.

The values in Table 23 for aluminium formed in an ammonium borate solution at 105 volts d.c. for 140 hours, and tested at 100 volts d.c., show that the leakage current increases, and the resistance of the active layer decreases, as the ambient temperature rises. They are due to Bairsto and Mercer ("Trans. Far. Soc.," 7, p. 1, 1911). The current-temperature relationship corresponds to an exponential curve ( $i = Ae^{kt}$ ), and for the figures given in Table 23,  $k = 2.049(0.085t)$ . The constant A seems to be independent of the electrolyte but dependent upon the formation time. The reverse holds good for "A." This is demonstrated by the values given in Table 24.

#### Dielectric Strength of the Anode Film

When the voltage across the anode film exceeds a certain value, sparking is observed to result at the surface. This voltage of breakdown according to Schulze is dependent upon the valve metal, upon the nature of the electrolyte and upon the concentration of the latter; it is independent of temperature and current density. Further, the maximum voltage that can be maintained across the film is dependent upon the nature of the electrolyte which is used for forming the film and upon the concentration of free ions in it. It appears to be independent of the valve metal, the current density and the temperature. Schulze, in "Elektrot und Maschinenbau," 27, p. 247, 1909, gives the maximum voltages for the film produced on aluminium in 0.1N solutions of various salts. These are reproduced in Table 25.

Schulze, in the treatise by Kosel and Pustet, also gives values for tantalum formed in 0.05N solutions containing metal-free hydroxyl, formate, propionate and phosphate ions. For these and the like, the maximum e.m.f. is about 480 volts. If the cation is not one of a heavy metal it has no influence. The maximum voltage is greatly influenced if there is a heavy metal in the anion complex; thus for tantalum in 1.05N

solutions of such anions the maximum voltage is about 100 volts or less, viz.:—

Chromium in di-chromate anion ( $\text{Cr}_2\text{O}_7$ )" 133 volts approx.

Iron in ferricyanide ( $\text{FeC}_6\text{N}_6$ )" 84 volts approx.

Platinum in platinumchloride ( $\text{PtCl}_4$ )" 28 volts approx.

Over the dilution range 0.5 to 0.05N an increase of about 1 per cent. in the dilution of the electrolyte produces an increase of about  $\frac{1}{4}$  per cent. in the maximum voltage; at very low concentrations, very high values up to about 1,900 volts may be attained.

For aluminium formed in ammonium phosphate solutions, W. R. Mott ("Electroch. Ind.," 2, p. 352, 1904) quotes an electric strength value of  $10^6$  volts per cm., and C. I. Zimmerman (Trans. Amer. Electroch. Soc., 7, p. 309, 1905) gives 5 to  $6 \times 10^6$  volts/cm.

#### Electrostatic Capacity of the Active Layer

Capacity measurements are relied upon as one means of estimating film thickness. Electrostatic capacity varies approximately inversely with the potential applied to form the film. For aluminium it amounts to 0.7 microfarads/sq. cm. for formation at 10 volts d.c. (Schulze, "Phys. Z.," 22, p. 146, 1921) and 0.18 mf./sq. cm. at 30 volts d.c. (Siegmund). In Fig. 108 the average results of several workers are expressed graphically, these applying to aluminium in aqueous electrolytes. N. A. de Bruyne and R. W. W. Sanderson ("Trans. Far. Soc.," 23, p. 42, 1927) investigated the rate of growth of the film on an anode of aluminium, and found that the reciprocal of the capacity increased to its final steady value approximately logarithmically with time.

When the voltage applied to an electrolytic cell is higher than that at which it was originally formed, the film adjusts itself to the new voltage. For a cell of large electrode surface, the increased voltage may cause a heavy flow of current, which in turn may result in overheating and damage to the cell if the readjustment to the film cannot occur with sufficient rapidity. A current limiting device has to be included in the circuit to protect against such a contingency.

On the other hand, a cell operated much lower than its forming voltage is characterized by a very slow readjustment to the new condition. Thus an electrolytic condenser with continued working gradually accommodates itself to the lower voltage and its capacity slowly increases due to a reduction in film thickness by virtue of electrolytic action. This rate of change is affected by temperature and by conductivity of the electrolyte; it is more rapid at high temperatures and conductivities. This is demonstrated by the curves in Figs. 107 and 108. Bairsto and Mercer concluded that the variation of capacity with temperature is a characteristic of the electrolyte.

Again, the capacity of an electrolytic condenser decreases with frequency. The change which occurs is greater for electrolytes of high specific resistance and for films formed at lower voltages.

The capacity/frequency characteristic of a new aluminium electrolytic condenser and on the same unit after a year's continuous service is shown in Fig. 110. The anode plates in this



case were corrugated, and this also influenced the fall in capacity.

#### The Electrodes

(a) The Anode. The purity of the metal used for the anode of electrolytic condensers and rectifiers is of first importance, having considerable influence upon the efficiency, life and corrosion of the cell.

For rectifiers, the copper content of aluminium is important and apparently a copper-free material is necessary. With copper up to 0.05 per cent. current delivery and life fall off rapidly, and with copper over 0.15 per cent.

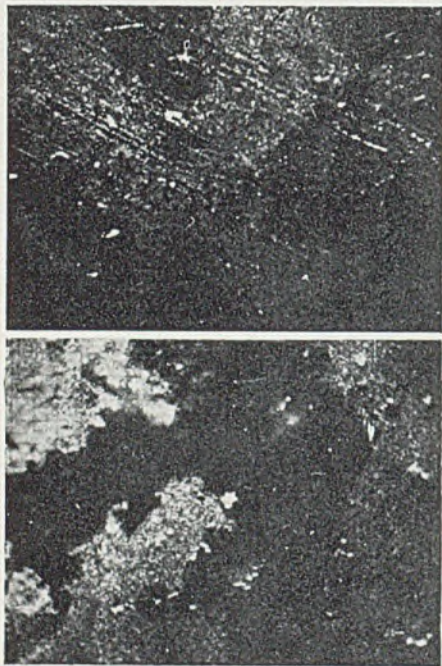


Fig. 124.—Photomicrographs ( $\times 50$ ) of corrosion, due to fibrous spacers in aqueous electrolytes, on formed aluminium anodes.

life is reduced disastrously (W. E. Holland, "Trans. Amer. Electroch. Soc.," 54, p. 232, 1928).

For condensers, Siegmund showed that the degree of purity of the aluminium affects the following factors:—(a) The formation time of the active layer; (b) the d.c. leakage of the film; (c) the number of cell failures from corrosion.

Formation is more rapid with aluminium of 99.6 per cent. purity than it is with that of only 99.1 per cent. The d.c. leakage is also lower with the higher purity metal; for aluminium formed at 60 volts for 24 hours, 99.1 per cent. purity material passed approximately 3 microamps./sq. cm. and 99.6 per cent. material passed only 0.5 microamps./sq. cm. The purer aluminium is said to be more readily corroded by the electrolyte, but in ammonium borate

electrolyte best results are said to be obtained with an aluminium of 0.24 per cent. silicon content.

Corrosion in electrolytic condensers shows itself by the pitting of the electrodes, the development of growths on the anode surface, and by the deposition of sludge. Corrosion may commence soon after the component has been placed in service, or it may be delayed for some months. Failure from corrosion may be rapid, but, on the other hand, corroded units may continue to function for some years. This may indicate that a corrosive influence can be eliminated or retarded with time by chemical action that produces a protective film over the affected area.

(b) The Cathode. A formed aluminium electrode when made a cathode offers only a small resistance to current flow if the voltage is above a certain minimum value. This minimum potential is dependent upon the valve metal, the thickness of the active layer, the nature and the concentration of the electrolyte, but it is independent of temperature.

The cathode or negative plate in a condenser operating on a d.c. circuit serves only to make contact with the electrolyte. It is not subjected to any intentional formation, but there is a tendency for a film to form on the cathode, assuming it to be a valve metal, during the periods of discharge. This can be overcome by using an inert, i.e., non-valve metal, or an aluminium alloy containing sufficient of an element such as silicon, which hinders film formation. Thus, with an alloy containing less than 99 per cent. of aluminium, it is possible to have a current density of about 1 milliamp. a.c./sq. cm. of negative plate without sufficient film forming to affect the capacity of the cell (Siegmund).

The Electrolyte. The formation of the active film on the anode takes place in both acid and alkaline electrolytes. Acid ions favour the formation of the insulating layer on an aluminium anode; alkaline ions favour its removal when the electrode is made a cathode. Provided a similar reaction occurs in each case at the anode surface, results with different electrolytes are fundamentally the same, but the electrical characteristics of the cell, e.g., resistance and power factor, may vary widely. Generally, the most suitable electrolytes have proved to be aqueous solutions of ammonium or alkali salts of weak acids, such as borates, oxalates, tartrates, citrates and salts of other organic acids. To augment formation of aluminium plates, C. Pollak adds about 3 per cent. of a chromate to an alkaline or neutral electrolyte (E.P., 23, 442, 1897, and 933, 1928). Bairsto and Mercer suggested ammonium molybdate solution as a suitable electrolyte. It does not follow that an electrolyte which is suitable for a condenser is suitable for a rectifier.

Ammonium borate has shown itself to be outstandingly good electrolyte for electrolytic condensers. Fig. 110, after Siegmund, shows the specific resistance values for solutions containing various portions of boric acid and ammonia. The acidity of ammonium borate solution decreases with increased dilution, as shown by the intersection of the dotted curve for constant ratio boric acid-ammonia, and the neutral solution, pH curve. The fact is also

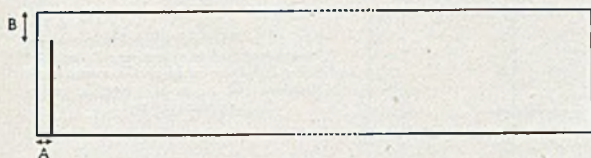


Fig. 125.—Method of making connection to anode foil.

shown that the specific resistance of the electrolyte is determined mainly by the ammonia content, and the acidity or alkalinity by the boric acid constituent. The control of the pH value of the borate solutions can be effected by adding certain sugars or glycerol (British Thomson-Houston Co., EP. 15,792, 1908).

The selection of an electrolyte for an electrolytic condenser has to take care of the following factors:—

1. Specific resistance of the electrolyte and its influence upon the electrical characteristics of the unit.
2. The corrosive action of the solution upon the metal of which the electrodes are composed.
3. The life of the solution, e.g., in the case of aluminium electrolyte condensers, the rate at which it becomes saturated with aluminium hydroxide, bearing in mind the fact that, during usage, the small current leakage is accompanied by a solution of the metal.

In general, as would be expected, the lower the specific resistance of the solution, the more rapidly does it become charged with aluminium hydroxide. This is clearly demonstrated by the practical data given in Table 26. At the same time, high specific resistance increases the electrical impedance of the cell.

Precipitation of hydroxide from aluminium electrolytic condensers is more rapid at higher

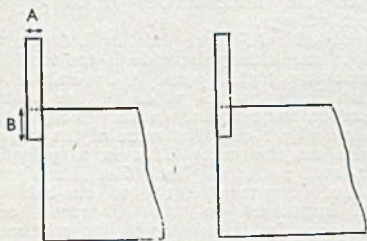


Fig. 126 (left).—Showing first fold according to method in Fig. 125. Fig. 127 (right).—Showing second fold in method according to Fig. 125.

temperatures. Again, deterioration occurs if the condenser is allowed to stand idle, because the electrolyte attacks the film.

*Effect of Impurities in the Electrolyte*

The formation of the anode film is highly sensitive to the presence of impurities, in some cases even in very minute quantities, in the electrolyte. Thus strong acids, heavy metals and halogen, nitrate and chlorate ions, destroy the unidirectional conductivity of an aluminium

cell. The following results from Schulze ("Z. Elektroch.," 20, p. 307, 1914) make it evident that extremely small amounts of foreign substances can interfere with the functioning of the cell:—Using an aluminium anode in a 0.22N borax solution, sodium chloride in a concentration of  $2.5 \times 10^{-4}N$  produces a noticeable retardation informing rate. This quantity is about 0.5 per mil. of the borax, and is sufficient to produce a turbidity with silver nitrate solu-



Fig. 130.—Showing arrangement of layers: A, anode; B, cambrics or paper; C, cathode. Arrow shows direction of winding or rolling.

tion. Any electrolyte giving this reaction should be rejected for purposes of electrolytic condenser or rectifier production. Bromine and iodine ions act similarly to the chlorine ions. The action of sodium nitrate is not so great; a concentration of 0.002N (equivalent to 1 per cent. of the borax) retards film formation. A slight alkalinity of the electrolyte is not objectionable, but strong alkalinity destroys the valve action. Sodium hydroxide in borax solution produces sodium metaborate. The metaborate is not hydrolyzed much more than the tetraborate, and, therefore, the sodium hydroxide does not become effective until its concentration exceeds that of the borax.

Table 27, after Bairo and Mercer, shows the enormous increase in leakage current of an aluminium anode when halogen ions are present, the aluminium anode being in ammonium phosphate, and formed at 110 volts d.c., the measurements being made at 20 volts d.c.

In the case of borax electrolytes, if a substance that itself will allow film formation but to a lesser extent than the borax does (e.g., a sulphate, an acetate, etc.) is added to the solution, it will exert an unfavourable influence. Taylor and Inglis ("Phil. Mag.," 6, 5, p. 301, 1903) have shown that those salts such as potassium chloride, potassium nitrate, etc., which destroy the functioning of an aluminium



Fig. 128 (left).—Side view of termination of electrode foils. Fig. 129 (right).—End view of termination of electrode foils: A, aluminium foil tab; B, tinned copper strip; C, tinned steel clip; D, braided flexible wire; E, soldered joint.

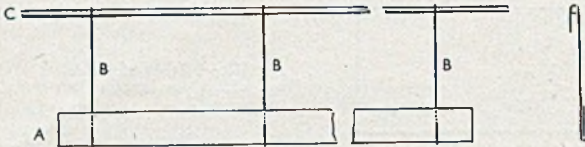


Fig. 131.—Method of holding anode lengths of foil for forming: A, anode foil; B, glass or phenolic resin suspenders; C, glass or phenolic resin supporting rod.

cell, are those that easily diffuse through an aluminium oxide membrane. Other salts that do not diffuse through are shown to be without effect.

*Condenser Properties of Formed Electrodes*

The work of C. I. Zimmerman ("Trans. Amer. Electroch. Soc.," 5, p. 147, 1904, and 7, p. 309, 1905), should be consulted for his exhaustive work on the electrical properties of the electrolytic condenser.

The active layer on a formed aluminium electrode constitutes an asymmetric dielectric in so far as it can retain positive charges only on the side in contact with the metal. A single-formed electrode immersed in an electrolyte constitutes an asymmetric cell. If compared with an ordinary mica or paper condenser, the metal anode and the electrolyte comprise the two conducting materials, and the active layer or film corresponds to the dielectric.

Two formed electrodes immersed in an electrolytic, consisting of two asymmetric cells in series opposed connection, are equivalent to two ordinary plate condensers in series, but the internal distribution of electrostatic charges is quite different from that which obtains in the condenser analogy, because of the rectifying properties of the film. The potentials are in opposition to one another in the two-electrode electrolytic condenser as contrasted with the series effect of the two potentials in the two-plate condensers. The condenser action of the two series-opposed asymmetric cells results from the energy changes accompanying the variations in distribution of the constant charge held by the unit. Such an arrangement will not pass d.c., whereas a.c. causes a leading current in the circuit of which the combination forms a part.

The behaviour of an electrolytic condenser consisting of two series-opposed asymmetric cells under the influence of an a.c. voltage is interesting. Current flows until the impressed voltage across the terminals of the cell reaches its maximum. When this is so, one electrode of the cell has maximum voltage applied to it, and, therefore, has maximum change. As the potential decreases from its maximum value,

the electrode that was positive starts to discharge current into the circuit, and the charge which is held starts to accumulate on the other electrode, which then thus becomes positive. For any subsequent variation in voltage, but for a given maximum applied voltage, the total coulomb charge remains constant. In contrast with this, the charge in an ordinary plate condenser varies with the applied voltage. In consequence of the constant electrostatic charge existing in the electrolyte cell, a uniform difference of potential is set up between the electrolyte and any point outside the cell in the external circuit which is neutral with respect to the a.c. pressure. The electrolyte is always negative with respect to the neutral a.c. pressure reference point. The arithmetical sum of the potentials across the two films is constant and equals the maximum volt-

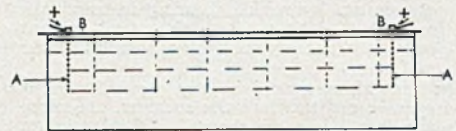


Fig. 132.—Showing anode foil in forming bath and folded end connections A-A, taken to anode connections B-B.

age impressed on the condenser terminals. The algebraic sum of the instantaneous values is equal to the instantaneous value of the impressed voltage.

The potential difference existing between the electrolyte and either electrode is the resultant of a uniform potential equal to one-half of the maximum instantaneous value of the voltage impressed on the cell, and an a.c. voltage equal to one-half of the effective value of the voltage impressed on the cell. This is a pulsating unidirectional pressure. Each film is subjected to an a.c. component equal to one-half the pressure impressed on the condenser, and, further, each film is subject to the maximum pressure impressed on the cell, instead of one-half, as is the case with two ordinary plate condensers connected in series.

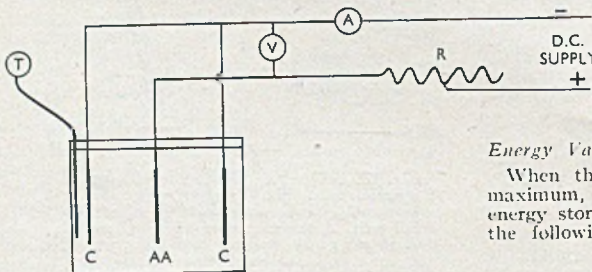


Fig. 133.—Showing arrangement for forming: Direct-current supply through variable resistance, R; A, ammeter; V, voltmeter; AA, anode foil; CC, cathodes; T, thermometer.

*Energy Variation Within the Cell*

When the charge on one electrode is at a maximum, that on the other is at zero. The energy stored at maximum voltage is given by the following expression:—

$$W_1 = 1/2 Q E_{max}.$$

Table 19.

| Voltage | Relative thickness $\delta/\epsilon$ |          |
|---------|--------------------------------------|----------|
|         | Aluminium                            | Tantalum |
| 50      | 6.4                                  | 4.1      |
| 100     | 10.3                                 | 7.1      |
| 150     | 16.1                                 | 11.6     |
| 200     | 22.3                                 | 17.0     |
| 250     | 29.3                                 | 22.9     |
| 300     | 37.1                                 | 28.8     |
| 350     | 46.6                                 | 34.6     |
| 400     | 58.0                                 | 40.3     |
| 450     | 71.0                                 | 45.0     |
| 500     | 85.9                                 | 49.1     |

$\delta$  = absolute thickness.  
 $\epsilon$  = dielectric thickness.

in which  $Q$  is the charge in coulombs and  $E_{\max}$  is the maximum voltage.

At the moment when the applied voltage becomes zero, each film holds one-half of the charge at one-half of the voltage, and the stored energy becomes:—

$$W_2 = 1/4 QE_{\max}$$

The energy variation is the difference between  $W_1$  and  $W_2$ , or  $1/4 QE_{\max}$ , or one-half of the total energy stored in the condenser when maximum voltage is impressed on the terminals. The contrast should be noted, viz:—An electrolytic condenser consisting of two asymmetric cells in series opposition stores and gives up only one-half of its total charge, whereas a plate condenser gives up its total charge. Further, in an electrolytic condenser one film charges while the other discharges, whereas in a plate condenser both electrodes charge and discharge together.

In the case where the two electrodes of an electrolytic condenser are not of the same electrostatic capacity, the charge stored in the condenser is independent of the capacity of the smaller electrode, and is determined solely by the maximum charge capable of being stored by the larger electrode. If one of the electrodes of the cell has negligible capacity, the unit no longer reacts on an a.c. circuit like an ordinary condenser, since it is able to receive charge but

is unable to return it. In this case, the potential difference between the smaller electrode and the electrolyte has a theoretical maximum value of twice the maximum pressure applied to the terminals.

#### Electrical Losses of the Electrolytic Condenser

The losses in an electrolytic condenser comprise the following:—

(a) A loss which is constant at all frequencies due to the inherent conductivity of the active film; this is equivalent to a high resistance in parallel with the capacity.

(b) A dielectric loss which, with ordinary types of electrolytic condenser increases with frequency.

(c) A loss due to the resistance of the electrolyte, i.e.,  $iR^2$  losses. The most suitable electrolytes have low conductivity (i.e., high resistance); these losses are appreciable. The electrolyte resistance remains almost constant over a wide range of frequencies.

(d) Losses due to electrolytic decomposition.

The composition of the electrolyte has a large influence upon the power factor of an electrolytic condenser when used on an a.c. circuit. Thus, Metropolitan-Vickers Electric (EP., 155,579) quotes a power factor of 40 per cent. for the electrolyte composition of 30 gm. of boric acid, 5 gm. ammonium borate and 1 litre of water, but with the addition of 4 gm. caustic soda and 0.5 gm. sodium fluoride the power factor falls to 4.2 per cent. Power factor increases with the applied a.c. voltage and with the time of the closed circuit. Schulze ("Elek. troc und Maschinenbau," 27, p. 247, 1909) used an aluminium condenser on a.c. It consisted of 10 aluminium plates of  $9.7 \times 16.5 \times 0.1$  cm. in saturated ammonium borate ( $\text{NH}_4\text{H}_2\text{B}_3\text{O}_4$ ) solution. Alternate plates were anode and cathode; his results are given in Tables 28 and 29.

Siegmund's condensers using ammonium borate solution of specific resistance 225 ohms showed power factors of the order of 9 per cent. at 60 cycles. Table 30 gives some values at different frequencies for capacity and the equivalent series resistance for this type of condenser.

Table 20.

| Time  | Forming current, $i$ mA. | Cell voltage, $e$ volts | Thickness of            |                                      | $\frac{e}{i} = r$ ohms | $\frac{r}{\delta}$ ohms/ $\mu\mu$ |
|-------|--------------------------|-------------------------|-------------------------|--------------------------------------|------------------------|-----------------------------------|
|       |                          |                         | Solid layer<br>$\mu\mu$ | Active layer<br>$\delta$<br>$\mu\mu$ |                        |                                   |
| 10"   | 100                      | 27                      | 113                     | 2.50                                 | —                      | —                                 |
| 30    | 100                      | 73                      | 160                     | 3.53                                 | —                      | —                                 |
| 40    | 100                      | 101.3                   | 270                     | 6.00                                 | $1.01 \times 10^3$     | $0.17 \times 10^3$                |
| 55    | 11                       | 101.3                   | 300                     | 6.62                                 | 9.22                   | 1.39                              |
| 90    | 4.1                      | 101.3                   | 305                     | 6.74                                 | 24.7                   | 3.67                              |
| 2'    | 3.1                      | 101.3                   | 307                     | 6.78                                 | 32.7                   | 4.82                              |
| 10    | 1.16                     | 101.3                   | 325                     | 7.17                                 | 87.2                   | 12.2                              |
| 60    | 0.54                     | 101.3                   | 335                     | 7.39                                 | 188                    | 25.5                              |
| 260   | 0.37                     | 101.3                   | 350                     | 7.72                                 | 278                    | 36.0                              |
| 450   | 0.25                     | 101.3                   | 355                     | 7.82                                 | 413                    | 52.8                              |
| 2,880 | 0.11                     | 101.3                   | 360                     | 7.93                                 | 922                    | 116                               |
| 7,340 | 0.07                     | 101.3                   | 390                     | 8.60                                 | 1,450                  | 169                               |
| 8,780 | 0.06                     | 101.3                   | 395                     | 8.72                                 | 1,582                  | 181                               |

12.5 cm.<sup>2</sup> tantalum in 0.05 N.  $\text{KNO}_3$ .

Formed at 100 V. d.c. Temperature 20°C.

Table 21.

| Voltage | Aluminium.<br>$\frac{e}{t} = r \text{ ohms.}$ | Voltage | Tantalum.<br>$\frac{e}{t} = r \text{ ohms.}$ |
|---------|-----------------------------------------------|---------|----------------------------------------------|
| 350     | $2.2 \times 10^1$                             | 200     | $0.21 \times 10^3$                           |
| 300     | 3.8                                           | 180     | 0.52                                         |
| 250     | 4.0                                           | 160     | 1.10                                         |
| 200     | 4.0                                           | 140     | 1.88                                         |
| 150     | 5.3                                           | 120     | 2.40                                         |
| 100     | 9.5                                           | 100     | 2.94                                         |
| 50      | 28.0                                          | 80      | 3.80                                         |
| 25      | 90.0                                          | 60      | 4.28                                         |
|         | *                                             | 40      | 5.00                                         |
|         |                                               |         | †                                            |

\* 1,000 cm.<sup>2</sup> of aluminium in ammonium borate solution. Formed at 350 V. d.c. (H. O. Siegmund).

† 12.5 cm.<sup>2</sup> of tantalum in 0.05 N. borax solution. Formed for one day at 200 V. d.c. (A. Günthe-Schulze).

Fig. 112 shows the percentage variation of these values with temperature.

N. A. de Bruyne and R. W. W. Sanderson suggested that an electrolytic condenser with two similar plates was equivalent to the network shown in Fig. 112, and for two electrodes of equal area this network reduces that shown in Fig. 113. The capacities are shown shunted by resistances to represent the leaky condensers at the electrodes. There is, however, no simple network capable of accurately representing the electrolytic condenser.

#### Application

The unidirectional current conducting characteristics of aluminium and tantalum anodes is applied to the rectification of alternating current in order to supply a source of direct current for battery charging. Best results for rectification are obtained with high current density at the anode, low inductance and low resistance of the external circuit, and low temperature. The e.m.f. of the rectified current is lowered by the capacity effect of the cell (A. Nodon, "Comptes Rendus," 136, p. 445, 1903). The  $i^2R$  losses are high, due to the low conductivity of the electrolyte and the low resistance of the active film. In using high current density, therefore, the heat generated due to these losses is confined to a small space and, in consequence, there is a large rise in temperature. This has to be offset by design features. Either the volume of the electrolyte must be kept large, or special provision must be made for cooling the electrodes or electrolyte, or a combination of these features must be embodied. The cathode in electrolytic rectifiers may be lead, iron or carbon or the metal container itself.

W. S. Horry ("Trans. Amer. Electroch. Soc.," 7, p. 237, 1905) refers to the use of the blocking effect of the electrolytic cell, due to the high resistance of the aluminium anode film, for preventing arcs or interrupting an inductive circuit. For this purpose, the breakdown voltage of the cell should be greater than the normal working voltage of the circuit. In the interruption of an inductive circuit, the high voltage surge breaks down the film, but this reforms when the circuit is operated again. Electrolytic lightning arrestors also utilize this breakdown characteristic of the aluminium anode.

The high electrostatic capacity available at

the anode of the electrolytic cell has caused large uses for static condensers. They cannot be used in a.c. circuits at high frequency because of high losses. Their chief usefulness is in low voltage circuits for protection against surges of steep wave front, and for use on d.c. circuits in which it is required to filter out a.c. ripple.

In telephone circuits, a smooth d.c. output is necessary so as not to interfere with conversations, and specially built generators have been used. An ordinary generator can be used for charging the exchange battery associated with telephone circuits provided it be used in conjunction with a filter circuit made up of chokes and condensers. These eliminate the a.c. ripple and thus prevent hum in the circuits (R. L. Young, "B.S.T.J.," 6, p. 702, 1927).

For use on a d.c. circuit, an electrolytic condenser needs only to have one of its electrodes constructed of a valve metal such as aluminium or tantalum, and the other may be a non-valve metal. The condenser action is maintained so long as the valve metal is kept positive. Such an arrangement on a.c. acts more as a rectifier.

L. Strasser ("E.T.Z.," 20, p. 498, 1899) shows how aluminium electrolytic condensers can be used for the production of high voltage d.c. A number of cells are connected in series and rapidly discharged in succession by means of a rotary commutator. Thus, the bank of cells is discharged in series.

Finally, the article states that the bulk and cost per microfarad of an electrolytic condenser are considerably less than those of an ordinary plate condenser operating at the same voltage. Efficiency is not so great at higher voltages, and here, therefore, the economy is not so apparent because the energy-storing capacity of a condenser varies as the square of the impressed voltage.

An account of recent researches on aluminium electrolytic condensers and modern views on their construction and operation is given by P. Robinson and J. Burnham in the "Journal of the Electrochemical Society," 1943.

In this the electrolytic condenser is considered in terms of its equivalent circuit, which consists of a condenser having aluminium oxide as dielectric, in series with one of which the dielectric is the solvent of the electrolyte. The aluminium-oxide dielectric is considered to be shunted by a high resistance which is substan-

Table 22.

| Voltage, D.C. | Current density, amp./1,000 cm. <sup>2</sup> |
|---------------|----------------------------------------------|
| - 6           | 0.8                                          |
| - 5           | 0.4                                          |
| - 4           | 0.1                                          |
| - 2           | —                                            |
| + 40          | 0.0001                                       |
| + 80          | 0.0005                                       |
| + 120         | 0.0015                                       |
| + 160         | 0.003                                        |
| + 200         | 0.005                                        |
| + 240         | 0.006                                        |
| + 280         | 0.007                                        |
| + 320         | 0.009                                        |

Aluminium formed in ammonium borate solution at 350 V. d.c.

tially the leakage resistance of the condenser. Likewise, the solvent dielectric is shunted by a resistance which is the resistivity of the electrolyte. In general, the paper discusses the characteristics of a condenser as functions of temperature and frequency in terms of the four variables, and also electrochemical interactions. Further, the electro-phoretic potentials of the various physical constituents of the condenser when immersed in electrolytes are discussed in relation to corrosion and related phenomenon.

The authors give an introductory review of the aluminium electrolytic condenser. Its name originates from the fact that it consists of an aluminium anode that has been subjected to a voltage in an electrolytic cell. When a d.c. voltage is applied to such a cell, the surface of the aluminium becomes electrolytically oxidized, and this process is normally called "formation."

Table 23.

| Temperature, °C. | mA./cm. <sup>2</sup><br><i>i</i> | Ohms/cm. <sup>2</sup>  |
|------------------|----------------------------------|------------------------|
| 15               | 0.0075                           | 13.3 × 10 <sup>6</sup> |
| 30               | 0.025                            | 4.0                    |
| 40               | 0.059                            | 1.60                   |
| 50               | 0.186                            | 0.54                   |
| 60               | 0.375                            | 0.27                   |
| 70               | 0.600                            | 0.17                   |
| 75               | 0.757                            | 0.13                   |

Aluminium formed in ammonium borate solution at 105 V. d.c. for 140 hours. Tests at 100 V. d.c.

Table 24.—Showing the constant "A" dependent on formation time, and "A" dependent upon the electrolyte composition.

| Electrolyte        | Time of formation    |                      |
|--------------------|----------------------|----------------------|
|                    | 8 hours              | 140 hours            |
| Ammonium molybdate | $i = 3.55e^{0.064t}$ | $i = 2.04e^{0.062t}$ |
| Ammonium borate    | $i = 3.55e^{0.085t}$ | $i = 2.04e^{0.085t}$ |

Once this process of formation starts and the oxide film is formed, it is irreversible. Consequently, terms such as current density, over-voltage, composition of the anolyte, have no definite significance. Again, impurities in the original aluminium anode are important, but so is their distribution in the metal surface. The thickness of the oxide film formed is a linear function of the applied voltage. It is of the order of 10<sup>-4</sup> cm. thick for 1,000 v. It is this very thin film that accounts for the high capacities per unit plate area.

In commercial practice, plain plate and etched plate condensers are referred to. This etching is a preliminary operation, which in effect increases the surface area and, therefore, greatly increases the capacity per unit of apparent area. The value of the condenser is dependent upon the electrical quality of the oxide film, and this is determined by the maximum formation voltage and the leakage current per microfarad. Desirable conditions, of course, are minimum leakage,

Table 25.—Maximum Voltages for Aluminium Formed in Various Electrolytes.

|                                        |       |
|----------------------------------------|-------|
| Sodium sulphate .. .. .                | 40 V. |
| Potassium permanganate .. .. .         | 112   |
| Ammonium chromate .. .. .              | 122   |
| Potassium cyanide .. .. .              | 295   |
| Ammonium bicarbonate .. .. .           | 425   |
| Sodium silicate .. .. .                | 445   |
| Ammonium phosphate (? dibasic) .. .. . | 460   |
| Ammonium citrate .. .. .               | 470   |
| Borax .. .. .                          | 480   |
| Citric acid .. .. .                    | 536   |

and the lowest value obtainable is dependent upon the chemical nature of the electrolyte. The maximum obtainable voltage is likewise dependent on the solution in which formed, and actually it may be expressed as some inverse function of the concentration of the solute.

The practical rating of an electrolytic condenser is a large fraction of the voltage to which the anode is formed. This formation voltage determines the voltage overload that can be withstood. Therefore, in a properly made electrolytic condenser, the voltage breakdown is accurately controlled by the manufacturing processes, and there is no question of designing the condenser to withstand a flash voltage of two or three times the working voltage as is the case with paper condensers.

Wet and dry electrolytic condensers are differentiated by the electrolytic solution in which they operate. A wet condenser uses a water solution as the electrolyte, and a dry one uses a non-aqueous electrolyte. The wet condenser has usually rigid electrodes comparatively widely separated. The dry condenser employs thin flexible metal strip electrodes with thin porous separators between them; the composite strip is wound on a mandrel into a compact cylinder, and subsequently impregnated with its non-aqueous electrolyte.

The application of electrolytic condensers is mainly determined by the large capacity for small space. Typical condensers consist of a filmed aluminium anode, a spacer impregnated with electrolyte, and an unfilmed aluminium cathode. For a.c. currents, two formed aluminium electrodes with electrolyte-saturated spacers between them are the fundamental form of construction.

The equivalent electrical circuit is given in Fig. 114. In this, C<sub>1</sub> is the condenser, with the dielectric consisting of the oxide film, and with the anode as one armature plate, and an imaginary conducting layer as the other. R<sub>1</sub> is the leakage resistance of the condenser. C<sub>2</sub> is the condenser with the dielectric consisting of paper saturated with electrolyte, with the

Table 26.

| Sp. resistance of ammonium borate solution | Approx. life at 25° C. before aluminium hydroxide separates out |
|--------------------------------------------|-----------------------------------------------------------------|
| 75 ohms.                                   | 1-1 year                                                        |
| 150                                        | 1-3 years                                                       |
| 300                                        | over 5 years                                                    |

Table 27.

| Electrolyte                                                            | Gm.<br>PO <sub>4</sub> ion<br>a | Gm.<br>Cl ion<br>b | Ratio<br>$\frac{a}{b} = \sigma$ | mA.<br>cm. <sup>2</sup> | Ratio<br>$\frac{i\sigma}{j_0}$ |
|------------------------------------------------------------------------|---------------------------------|--------------------|---------------------------------|-------------------------|--------------------------------|
| 130 c.c. NH <sub>4</sub> NaHPO <sub>4</sub> .. ..                      | 0.59                            | —                  | —                               | 0.0013                  | 1                              |
| 130 c.c. NH <sub>4</sub> NaHPO <sub>4</sub><br>+ 3½ c.c. KCl aq. .. .. | 0.57                            | 0.048              | 0.084                           | 0.157                   | 121                            |
| + 4½ c.c. KCl aq. .. ..                                                | 0.57                            | 0.062              | 0.109                           | 0.26                    | 204                            |
| + 5½ c.c. KCl aq. .. ..                                                | 0.56                            | 0.076              | 0.136                           | 0.471                   | 362                            |
| + 6½ c.c. KCl aq. .. ..                                                | 0.56                            | 0.090              | 0.161                           | 0.972                   | 750                            |
| + 7½ c.c. KCl aq. .. ..                                                | 0.56                            | 0.105              | 0.191                           | 1.89                    | 1,450                          |

Aluminium anode formed at 110 V. d.c.

Measurements made at 20 V. d.c.

cathode as one plate and an imaginary conductor of Cr as the other, R<sub>2</sub> is the resistivity of the electrolyte.

From mathematical considerations of these, Robinson and Burnham give Figs. 115 and 116 to show capacity changes with frequency and dissipation factor changes with frequency.

With regard to the formation of the oxide film, this is substantially in accordance with Faraday's laws of electrolysis; 95 per cent. electrolytic efficiency is obtained.

The oxide film has been reported as of crystalline structure essentially cubic. There is, however, much doubt on this, and the present authors finally concluded that it is probably of an amorphous nature. They found the film to be birefringent and, therefore, the crystal to be of lower symmetry. They illustrate the birefringence as shown in Fig. 117. In A is a microphotograph of the film in transmitted light between crossed nicols. In B is shown the grain structure of the surface of the aluminium electrode. The authors stress that the striking parallel between the mosaic pattern in the two photographs indicates that the orientation of the aluminium oxide crystals is determined by the crystal face that the metal presents to the solution. The fact that thick films are homogeneous in conjunction with the properties of the film, such as its ability to absorb dyes, etc., strengthens the belief that the film is amorphous.

Factors such as effect of pressure and electrolyte resistance on breakdown of aluminium anodes and design factors in relation to capacity, power factor, temperature effects, are considered in detail.

Fig. 118 gives relation between dissipation factor and voltage rating for etched plates and for plain plates. This shows the importance of the ratio of actual surface area of the anode to

geometrical area. Fig. 119 shows change of power factor and of capacity of dielectric condensers with temperature as a function of the voltage rating. Fig. 120 shows the change in the ratio of low temperature to room temperature impedance with temperature of dry electrolytic condensers as a function of voltage rating.

Much attention is given to corrosion and electrokinetic properties, and some very sound data are presented. It has already been stated that Faraday's law of electrolysis holds good in the ideal case, and it should hold good very closely in practice. In some instances it is found that the current efficiency is low, and 30 per cent. reduction is quite common. This can occur due to impurities in the aluminium or impurities in the electrolyte. For example, 0.1 atomic per cent. of iron in the aluminium is sufficient to lower current efficiency by 30 per cent. Soluble sulphates, and still more so chlorides, are also known to give reduced current efficiency and to cause very high leakage current in the final condenser. A phenomenon associated with the presence of these elements is often referred to as corrosion. Usually this corrosion shows its influence after the condenser has been standing idle. Despite the fact that it is an easy matter to observe the effect of impurities such as iron in the aluminium or chloride in the electrolyte in a qualitative sense, it is very difficult to measure the effects quantitatively and even more difficult to account for them. The authors, therefore, investigated the effects of impurities in terms of electrokinetic relationships existing in the condenser. They point out that in most electrochemical devices the electrolytes are fairly good conductors and the electrokinetic effects are slight, whereas in the electrolytic condenser the electrolytes are rela-

Table 28.

| Condenser         |                 | Losses,<br>watts. | Calculated<br>capacity<br>mF. | Power<br>factor | Temp.<br>°C. | Formation<br>voltage<br>d.c. | Residual<br>current at<br>d.c. forming<br>voltage<br>amp. | Peak value<br>of applied<br>a.c. | Time of<br>closed a.c.<br>circuit,<br>mins. |
|-------------------|-----------------|-------------------|-------------------------------|-----------------|--------------|------------------------------|-----------------------------------------------------------|----------------------------------|---------------------------------------------|
| Current,<br>amps. | Voltage<br>a.c. |                   |                               |                 |              |                              |                                                           |                                  |                                             |
| 1.26              | 27.4            | 2.25              | 146.3                         | 0.065           | 19.7         | 40                           | 0.003                                                     | ca. 33                           | 120                                         |
| 1.35              | 59.2            | 4.0               | 72.6                          | 0.050           | 18.0         | 80                           | 0.0045                                                    | ca. 84                           | 60                                          |
| 1.72              | 113.4           | 23.0              | 48.2                          | 0.118           | 22.8         | 160                          | 0.0037                                                    | ca. 159                          | 60                                          |

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| 8P1   | Paper—Glossy.<br>Blue sensitive.<br>High speed.<br>High contrast.          | Very widely used for recording blue fluorescent screens and also for many other forms of recording where a paper base is required. Approximately the same speed as 5B51 film.                                                                                                                                    |
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tively poor conductors and the electrokinetic effects are quite marked. The average currents are low, but the current density at a particular point may be high. Again, the amount of material transported by electrophoresis may be 100 times the weight of ions carrying the current.

For preliminary experiments a formed anode was dissolved in hydrochloric acid, leaving the film in suspension. This film was washed by electrodecantation with water and then with borax solutions. The migration of the pieces of film so prepared were observed. It was established that the electrokinetic properties of the film were closely the same as those for

Table 29.

| Calculated capacity. mF. | Voltage. A.C. | Current. Amp. | Losses. Watts | Power factor |
|--------------------------|---------------|---------------|---------------|--------------|
| 43.9                     | 102.8         | 1.42          | 8.6           | 0.059        |
| 43.9                     | 82.8          | 1.14          | 5.0           | 0.053        |
| 43.8                     | 73.6          | 1.01          | 3.5           | 0.047        |
| 43.6                     | 59.2          | 0.81          | 1.7           | 0.041        |

aluminum, and, consequently, the work was continued, using aluminum diaphragms. The zeta potential measurements were made by applying a voltage across a porous aluminum diaphragm and measuring the rate of electro-osmosis of the solution through the diaphragm. The actual measurement recorded was the time required for the meniscus of the liquid to move through a unit distance. Under these conditions the rates of osmosis are approximately proportional to the zeta potentials.

Fig. 121 shows the relative zeta potentials of aluminum oxide in boric acid and water solution, to which various concentrations of ammonia were added. It is important to note that the potential of the film was negative at all concentrations, indicating that the tendency of the film when a voltage is applied is to stay on the anode. It was also observed, although it may only be a coincidence, that electrolytes which impart the highest potentials to the film are those which give the best shelf life in wet electrolytic condensers.

In another series of tests, a boric acid solution which gave a negative zeta potential was used, and to it was added thorium nitrate: 0.017 gms./litre of thorium nitrate was found to give a maximum positive zeta potential. This was followed by experiments, using boric acid solutions containing ferric iron, aluminium, lead and calcium. Results are shown in Fig. 122 for the change in electrokinetic potential with concentration of the added ion. In the case of iron, it is seen that it imparts a large positive potential to the aluminium. It can be assumed, therefore, that the influence of iron impurity in the aluminium is for some of it to be oxidized to ferric iron, which, when it is transported to the cathode, carries possibly 100 times its weight of aluminium oxide. This is supported by the fact that using aluminium containing 0.1 to 0.3 per cent. of iron, the current efficiency in forming is approximately proportional to the iron content.

The influence of the aluminium ion seems anomalous because some aluminium ions must

be present in the electrolyte. It should have a drastic effect similar to thorium. However, if to the solution illustrated in Fig. 122 which gives the maximum positive potential, ammonia is added, the potential falls and then becomes negative as aluminium precipitates as hydroxide. This shows why no troubles are encountered in commercial electrolytes from this phenomenon. Commercial electrolytes have a pH value close to the isoelectric point of aluminium hydroxide, and at that point the equilibrium concentration of aluminium is a minimum. Average conditions, therefore, are such as to suppress the aluminium ions. The effect of any impurities which permit the formation of aluminium ions will be severe. It is probably in this direction acidic ions such as chloride ion are so detrimental, i.e., that a local concentration of chloride ion which increases permissible concentration of the aluminium ion, causing disintegration and migration of the film in such areas.

Regarding air-line corrosion, the authors consider that, below the air line, aluminium oxide has a strongly negative potential, and at the air line the potential is nearly zero. Air-line corrosion does exist. Electrokinetic considerations also explain the failure in substituting an aqueous electrolyte in a dry condenser. In short, it is not practicable to take a dry

Table 30.

|                              | Frequency | Initial value | Value after one year's service |
|------------------------------|-----------|---------------|--------------------------------|
| Capacity                     | 60        | 640mF.        | 930mF.                         |
|                              | 400       | 570           | 860                            |
|                              | 1,000     | 540           | 840                            |
|                              | 2,000     | 520           | 830                            |
| Equivalent series resistance | 60        | 0.37          | 0.27                           |
|                              | 400       | 0.15          | 0.125                          |
|                              | 1,000     | 0.14          | 0.12                           |
|                              | 2,000     | 0.12          | 0.11                           |

Condenser formed at 100 V. d.c. and operated continuously for one year at 66 V. d.c. (Values have been read from a small scale graph.)

condenser and impregnate it with the same electrolyte used in a wet one.

Fig. 123 gives their measurements for aluminium oxide and for cellophane in 10 gms./litre of borax in water and then replacing the water gradually by glycerine. It is seen that in the water solution, both cellophane and aluminium oxide have negative potentials. Therefore, with a "dry" condenser impregnated with "wet" electrolyte, during operation the cellophane would plate out on the anode and would interfere with the normal functioning of the anode. This causes corrosion, as shown in Fig. 124.

In the glycol-rich solutions, cellulose has a positive potential, with aluminium oxide negative. Consequently, an anode in such an electrolyte would be uncontaminated by any cellulose. Dry commercial condensers use a glycol-rich electrolyte, the water content being well below the limit indicated in Fig. 123, and the salt content much higher. Ruben's patent U.S. No. 1,891,207 covers this aspect.

(To be continued.)

# Aluminium in The Chemical Industry

*In This, the Final Part of the Account Concluded from "Light Metals," 1944/7/551, the Applicability of Aluminium for the Construction of Various Items of Apparatus for Specific Purposes in the Fine and Heavy Chemical Industries is Examined*

FOR many years past, the value of aluminium in the handling of concentrated nitric acid and nitrous fumes has been recognized by the large producers of the acid who have made extensive use of the metal in the construction of their plant and transport equipment.

In order to understand the basis on which aluminium is able to take such an important place in the industry, it may be advisable to recapitulate and to comment on the information given earlier in this article relevant to the effect of nitric acid on aluminium. A curve was developed showing reduction in thickness of aluminium plates of 99.3 per cent. purity when immersed in nitric acid of different concentrations for a period of four weeks. This is only one of a number of graphs which have been published, and these several curves are not all in complete agreement, as might be expected when it is appreciated that the purity of the nitric acid is not taken into consideration. That cited indicates a maximum reduction of 0.0064 in. corresponding to a concentration of 30 per cent. acid by weight, i.e., maximum attack takes place at this concentration. In some cases the maximum rate of attack has been stated to be higher (0.0087 in. in one case) whilst, in other instances, it has been lower, but, in all cases, the curves do show that maximum attack takes place at concentrations between 15 and 50 per cent. nitric acid and that outside this range, and particularly near the two ends of the scale, attack is slight. The figures given for reduction in thickness in very dilute or concentrated acid, which is what we are most concerned with here, are invariably in good agreement.

In designing aluminium chemical plant, it is generally considered that, for heavy plant of a permanent nature, the maximum loss in weight by chemical attack which can be sustained economically and technically per day is 1 gm. per sq. m. of exposed surface area. Reference to the graph supplemented by calculations involving the density of aluminium shows that this rate of attack occurs with acid of about 1 per cent. or 80 per cent. concentration and that at 90 per cent. concentration and above, the rate of attack is scarcely more than half the limiting figure. It is with nitric acid, substantially free from impurities, particularly sulphuric acid and chlorides, of concentration

above 90 per cent. by weight and, occasionally down to 80 per cent. by weight, that aluminium equipment is employed and, in this capacity, it gives better service and greater all-round satisfaction than any other available material.

The rate of attack increases with rise in temperature and is greatly accelerated by the presence of impurities such as chlorides, free sulphuric or hydrochloric acid, and copper salts. The content of these materials must not be allowed to exceed a very small figure (around 0.01 per cent.) or the dangerous pitting type of corrosion may ensue. The presence of dissolved lower oxides of nitrogen is also detrimental; it is due to the formation of these lower oxides in still acid that aluminium is attacked to a greater extent by still acid than by acid which is kept in motion. Stirring vanes are commonly fitted to aluminium tanks in which nitric acid might otherwise remain undisturbed for a time. Dry nitrogen oxides are not very corrosive, although the moist gases are more so and may occasionally exert a vigorous attack. Nitrous acid exerts only a slight attack on aluminium.

In the early days when light metals first made their appearance in the nitric-acid industry, metal of 99.3 per cent. purity was the best that could usually be obtained. In recent years 99.5 per cent. metal has been used, but the superior corrosion resistance of the 99.8 per cent. metal, now so generally available, should ensure even greater satisfaction of aluminium equipment than in the past. It is unfortunate that no immunity to attack or substantial reduction in the rate of attack is provided by M.B.V. or anodic treatment as the coatings produced are dissolved by the acid. The rate of attack does not diminish with time, showing that the metal does not become passive.

## *The Manufacture of Nitric Acid*

Nitric acid is made on a large scale by three methods, (a) from sodium nitrate, (b) by the electric arc process, (c) by the oxidation of ammonia. In the first process sodium nitrate is heated with concentrated sulphuric acid in a large cast-iron retort set in brickwork, the nitric acid is distilled off and is condensed in tubes cooled partly by air and partly by water, whilst oxides of nitrogen formed are absorbed by water in a stoneware tower packed with hollow stoneware cylinders or balls. The whole process

may be carried out under reduced pressure when the reaction takes place more rapidly and at a lower temperature, with consequently less decomposition.

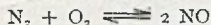
Aluminium is employed for the construction of plant used in this method of production to a smaller extent than in the other two methods of manufacture due mainly to the presence of sulphuric acid which, as previously stated, greatly increases the corrosive attack of nitric acid on aluminium. Thus, the retort is made of cast iron, a material which, although dissolved by liquid nitric acid, is unattacked by nitric-acid vapour and is fairly resistant to concentrated sulphuric acid, probably due to the formation of a protective coating. The condenser often consists of stoneware U-tubes, horizontal glass tubes or S-shaped tubes of silicon iron, but aluminium has been employed satisfactorily for the construction of these condenser tubes where the design of the plant is such that little sulphuric acid is carried over as far as the condensing apparatus. The metal has also been used satisfactorily for the construction of the absorption towers, although these are more frequently made of stoneware.

For running off the concentrated acid and for storing and transporting it, aluminium piping, tanks, drums and other containers are commonly employed and have given every satisfaction.

#### The Arc Process

At the high temperature of the electric arc, atmospheric nitrogen and oxygen unite to form oxides of nitrogen which may be absorbed to give nitric acid. This process was first worked experimentally at Manchester in 1900 and later developed in Norway from 1902 onwards, using electricity from hydro-electric schemes.

In this process a furnace is formed by the arc burning between two water-cooled copper poles, the arc being spread out into the form of a disc by means of an electro-magnet. Air is drawn through this flame, which is at a temperature of about 3,000 degrees C., and combination occurs between the oxygen and the nitrogen:—



The reaction is reversible, the equilibrium concentration of nitric oxide at 3,000 degrees C. being about 5 per cent. by volume, but only 0.4 per cent. at 1,500 degrees C. The gases leaving the furnace are, therefore, very rapidly cooled to about 1,000 degrees C. to fix the equilibrium, and a yield of about 1 per cent. nitric oxide is obtained. Further cooling is carried out in two stages, first to 150 degrees C. in a heat exchange apparatus in which steam is generated which is later used to evaporate solutions formed in the course of the operations; then to 50 degrees C. in large pipes exposed to the air.

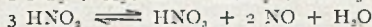
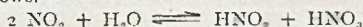
Right from the early days of the process aluminium has been the material chosen for the construction of these pipes due to its resistance to the gases coupled with its high thermal conductivity and the ease with which the pipes can be formed and connected. Aluminium would not be suitable for the previous stages of cooling due to the high temperatures involved.

When the gases have cooled below 600 degrees C. formation of nitrogen dioxide begins:—



This is a somewhat slow process and, to give the reaction time to go to completion, the gases are passed through a large empty iron "oxidizing" tower before going on to the absorption towers. It is suggested that the use of a sheet aluminium lining to the iron oxidizing towers would be advantageous.

The absorption towers are gigantic affairs, usually three or four in number, 65-80 ft. high and 18 ft. in diameter, built of granite slabs and packed with broken quartz. The usual arrangement is to employ four towers in series, through which the gases are passed in turn. Water is fed into the top of the last tower to be reached by the gases and the weak acid which collects at the bottom is fed into the top of the third tower, and so on, so that the solution leaving the first tower is the most concentrated, having run counter current to the gas stream. The formation of the acid takes place as follows:—



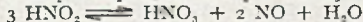
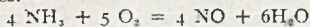
The nitric oxide is re-oxidized by the excess of air present, forming nitrogen dioxide which re-enters the solution.

For the apparatus required for absorption, aluminium is unsuited because the concentration of acid involved is within the range most dangerously corrosive to the metal; neither is it suitable for use in the concentration apparatus, as concentration is carried out in the presence of sulphuric acid.

#### The Oxidation of Ammonia

The catalytic oxidation of ammonia is the most important industrial process for the manufacture of nitric acid and is one in which aluminium finds extensive application in such components as reaction vessels; absorption columns; cooling coils for the concentration of the acid; digesters; pressure piping; storage and transport tanks; and piping for nitrous gases.

This process is based on the fact that if a mixture of ammonia and air or oxygen is passed over a suitable catalyst, generally heated platinum, the ammonia becomes oxidized to nitric oxide which, on cooling, undergoes spontaneous further oxidation to nitrogen dioxide, after which the gas may be absorbed in water with the formation of nitric acid, as in the arc process:—



In general, all plant which comes into contact with nitrogen oxides, nitric acid or the initial gases is made of aluminium, partly because of the excellent service which it gives under corrosive conditions, partly because of its advantageous thermal characteristics, and partly because aluminium piping and tubes are so readily formed to shape, connected, and, when necessary, replaced. But the main impetus to the use of aluminium was the demand for an acid free from heavy metal contamination which would, therefore, ensure freedom from the danger of spontaneous explosion in products, such as ammonium nitrate explosives, made from the acid.

The best results are obtained when the gas

passes rapidly over the catalyst; with a slow current of gas, much free nitrogen is formed. A mixture of pure ammonia gas with twice its volume of oxygen and sufficient steam to render the mixture non-explosive, or, alternatively, a mixture of 1 volume of ammonia gas and 7.5 volumes of air filtered free from dust (in aluminium dust precipitation equipment) are passed through aluminium pipes to the catalyst chamber. This, in its most usual form, consists of a rectangular aluminium box across which a series of fine aluminium gauzes are stretched. The mixture of gases is passed very rapidly through the box, which is heated electrically. Alternatively, the gas stream may be heated to 500 degrees C. before passing into the apparatus, when the reaction proceeds automatically, without the application of further heat. The efficiency of the process is such that more than 90 per cent. of the ammonia is converted into nitric oxide and, with the mixture of ammonia and air, 1 sq. ft. of double catalyst gauze will produce seven tons of nitric acid in 24 hours.

The oxides then pass to two cooling towers arranged in series. In the first tower they are cooled by passing over aluminium pipes through which water is circulated, whilst, in the second tower, the operation is repeated except that refrigerant is pumped through the aluminium pipes to liquefy the bulk of the nitrogen dioxide passing through the tower. A 26 degrees Ré solution of calcium chloride is the most frequently used refrigerant, and aluminium is generally satisfactory in contact with it; in practice, however, additions of 1-2 per cent. sodium dichromate inhibitor are added to the refrigerant and these greatly increase the life of the aluminium apparatus.

From the cooling towers the liquid product is taken in aluminium pipes to storage tanks constructed of welded aluminium and fitted with agitating devices to keep the liquid in motion.

The vapours which escape liquefaction in the cooling towers are rich in nitrogen pentoxide and are absorbed in concentrated nitric acid in absorption towers constructed entirely of aluminium. Residual oxygen, nitrogen, ammonia, water vapour and inevitably, droplets of nitric acid, pass into the atmosphere.

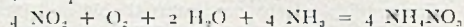
From the storage tanks the flow diagram divides according to whether it is desired to produce pure nitric acid or an inorganic nitrate. If the former is to be made the liquid nitrogen dioxide is pumped to an autoclave in which it is oxidized under pressure and in the presence of water to form what is known as red acid, consisting of concentrated nitric acid containing dissolved oxides of nitrogen (nitrogen dioxide and pentoxide). These oxides are removed by passing the acid through a bleaching column, or steam jacketed tower, maintained at a temperature of 100 degrees C., when they boil off and are returned to the cooling towers for further cooling and refrigeration. The bleaching column or tower is of all-aluminium construction, whilst the pump which drives the liquid nitrogen dioxide into the autoclave contains many parts in aluminium alloy. The acid is finally cooled in aluminium heat exchange apparatus and stored in aluminium tanks fitted with aluminium stirring apparatus to remove any lower oxides of nitrogen which may be formed, and are finally transported in aluminium tank cars and wagons, drums and

smaller containers. It has already been told how the need for a nitric acid free from heavy metal contamination led to developments and improvements in the drums and other aluminium containers then being made for acetic acid. The remarks made about other types of containers for acetic acid apply with equal force to those intended for use with nitric acid, which really run along parallel lines.

Aluminium syphons are among the auxiliary equipment used in the manufacture of nitric acid.

If, on the other hand, it is desired to produce an inorganic nitrate, the cooled nitrogen dioxide (liquid or gas) is led into a suitable solution of the desired metallic radical. For example, to form calcium nitrate, the nitrogen dioxide is passed through milk of lime to produce first a mixture of calcium nitrate and nitrite and, later, nitric acid, which converts the nitrite present into nitrate.

Ammonium nitrate, an important constituent of explosives, is formed by blowing ammonia gas mixed with air and steam into the cooled and fully oxydized gas stream. The reaction takes place as follows:—



Solid ammonium nitrate is deposited as a powder. Alternatively, the product may be made by neutralizing nitric acid with ammonia or ammonium carbonate, or by other means. Whichever method is employed, aluminium has proved invaluable as a material of construction for the vessels employed since traces of aluminium which may pass into the crystallized product are not catalytically active and do not render the nitrate unstable. This greatly reduces the danger of spontaneous detonation of ammonium nitrate explosives, such as has been encountered when traces of other metals have been present.

A striking feature about aluminium equipment in the nitric acid industry is the size of some of the plant employed. This will be apparent from the fact that storage tanks with capacities of 18-25 c.m. are common in France. Railway tank wagons for use on the lines operated by the Campagnie du Chemin de fer du Nord were limited to 13 cubic metres, and were built of aluminium sheet 14 to 16 mm. thick. Aluminium is used for the conveyance of pure nitric acid and silicon iron for sulpho-nitric acid.

Containers for nitric acid are fabricated by welding and, because of the high performance desired, the greatest care and skill are required in the welding operation. Only autogenous welding should be employed. It is essential that the weld metal is homogeneous in structure and free from pores. Porosity is avoided most easily when using sheets about 6-7 mm. thick. The weld must also be free from flux and oxide inclusions. It should not be left in the as-welded condition, in which it is less resistant to corrosive attack, nor should it be roughly hammered.

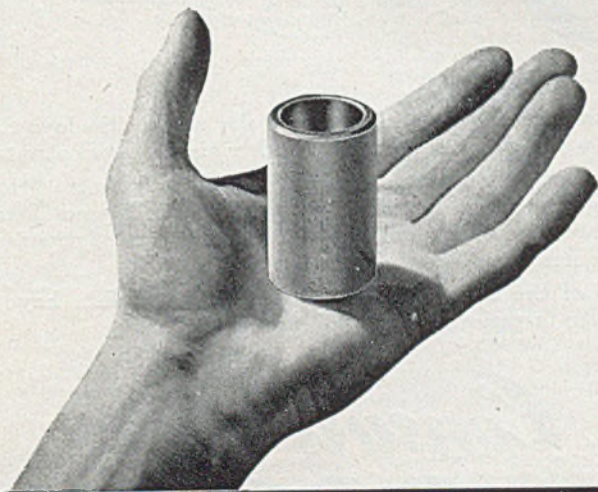
The surface of the weld should be ground and thoroughly washed to remove flux, which tends to concentrate on the surface. The seam should then be lightly hammered and well annealed by means of a blow-pipe at a temperature of about 350-400 degrees C. This is always advisable even with the thinner grades of sheet, but with metal thicker than about 6-7 mm. it is

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#### *Light Metals in the Petroleum Oil Industry*

It is now generally recognized in the oil industry that, in certain directions, the use of aluminium and aluminium alloys is definitely advantageous. Although the tonnage of metal thus consumed is not large to date, there is every reason to expect a considerable expansion in the utilization of light metals after the war.

The advantage to be gained by the use of aluminium is mainly a reduction in upkeep expenditure due to the high resistance of the metal, compared with that of iron and galvanized iron, to the corrosive substances that are present in crude and partly refined oils. Particularly does this apply to high sulphide oils which are notoriously hard on iron but with which aluminium has given a very satisfactory life. Occasionally the low density of the metal is of importance, as, for example, in gauging equipment, dippers and transportation equipment; in other cases the high thermal conductivity of the metal is beneficial.

From the chemical point of view aluminium is unattacked by gaseous liquid or solid hydrocarbons, aliphatic or aromatic, and is generally unattacked to any serious extent by inorganic or organic sulphur compounds. Its use, therefore, in contact with crude oil composed of hydrocarbons which are soluble in each other, and more or less mixed with sand, sulphur, oxygen and nitrogen compounds with water would appear to offer many advantages as regards resistance to corrosion and consequent length of life.

*Extraction of the Oil.*—It is not known how far aluminium has any application in the air lift operations of oil wells, but it is believed to be very small at the moment. Nevertheless, the idea commends itself for consideration because of the considerable success which has attended the use of aluminium tubing in similar operations in sulphur wells where the metal is employed in much the same way as in oil wells and is exposed to the same corrosive agents, namely, water of high salt content, sulphur (molten in this case), sulphurous gases, chiefly hydrogen sulphide, and ordinary atmospheric conditions. Actually the conditions in oil mining are less corrosive than those attending the mining of sulphur with aluminium tubes since the latter operation is carried out at a temperature in excess of 250 degrees F. It is possible that the disastrous corrosion of ferrous metals experienced by the sulphur industry has not been felt to anything like the same extent by the oil industry and hence the comparative lack of interest in aluminium oil-winning equipment. Nevertheless, taking a long-term point of view, it might be an ultimate economy to make use of aluminium protection in some form or other, by using aluminium alloy tubes or, more likely, by employing a lining of aluminium either in the form of a thin wall or as a thick metallized coating.

Where the crude oil is mixed with such a large quantity of sand as to render pumping impossible and to necessitate the use of some sort of lading or dipping equipment, winning of the oil may be simplified by the use of an aluminium alloy ladle. In this instance lighter

weight necessitates less energy for the windlass or, alternatively, a ladle of greater carrying capacity can be fitted without altering the remainder of the plant. In either case the use of aluminium in place of heavy metal effects an appreciable reduction in working costs.

*Flow Tanks.*—From the well, the crude oil passes first to flow tanks. These are relatively small structures, generally of about 550 barrels capacity, in which the oil is kept for a short time before passing on to main storage tanks. In the flow tanks, much of the sand and coarser suspended matter precipitates to the bottom and, with the frequent presence of brine, which sinks and forms a layer between the precipitated matter and the oil, and the sulphurous materials present in the oil, the container metal is exposed to considerable hazards, both mechanical and chemical. Great trouble has been experienced with iron flow tanks. The sulphurous gases collect at the top and attack the metal, forming loose ferrous sulphide scale, which then falls down into the brine layer and gives rise to electrochemical corrosion of the lower part of the container wall. The solution to the difficulty appears to lie in the use of aluminium either for the whole tank or at least for the top, sides and roof. In this way the elimination of sulphide scale is ensured and galvanic corrosion prevented. Results of numerous installations of riveted or welded flow tanks of aluminium or aluminium alloy have shown that the light metal is entirely satisfactory. It is now becoming quite customary in new plant to install all-aluminium flow tanks, and it has been proved that, although the initial cost is greater, the longer life of the tank and the smaller leakage, especially under severely corrosive conditions, entirely justifies the added capital investment. The success of aluminium in this connection suggests its application in other items of plant, such as gas separators and electric dehydrators, where resistance to the corrosive action of well fluids after they have left the well is of importance.

The storage tanks present a different problem economically because of their huge size, often 55,000 barrels or more. These tanks suffer from the same corrosion troubles as the flow tanks, perhaps to a slightly less degree, but, on the other hand, leakage is a far more serious and expensive matter, and the corrosion of large storage tanks for both crude and refined products regularly causes great losses of material. Unfortunately, the size of the container makes the cost of all-aluminium equipment impossibly high, even if the project were possible technically, but there are a number of important measures which can be, and often are, taken to reduce corrosion by the use of aluminium.

Chief among these is the use of aluminium in the roof construction, using one of a number of methods. The roof may consist of wooden trusses and purlins over which heavy-gauge aluminium sheeting may be fixed, or the aluminium may be applied in the form of foil on the underside of a wooden decking or of a covering of roofing felt. In other cases, a thick coating of aluminium may be applied to the underside of a roofing of sheet iron by spraying. Adequate protection to the inside walls of an iron tank is given by aluminium foil applied over an adhesive paint on the steel wall, in



much the same way as wall paper is applied to plaster walls. Wooden roof construction is no longer employed in this country, owing to the added fire hazard, although it is still being used to a small extent in the U.S.A. Current practice in this country is to employ all-steel tanks, the inside lower walls of which are protected by a cement wash; it is admitted that extensive and serious corrosion occurs and that frequent renewal of the cement work is a messy and inconvenient operation.

The piping connecting the flow tanks to the storage tanks and which transports the oil through the plant in which it is distilled, filtered, etc., may be of aluminium. Tubes up to 10 ins. in outside diameter are available commercially, but larger tubes can be made without much difficulty by forming and welding or riveting sheet metal. Where piping passes underground the metal needs to be protected by the application of a thick coating of bituminous paint. As an added precaution, however, aluminium foil should be wrapped round the outside of the pipe to seal cracks in the bituminous coating which form inevitably as the pipe beds down.

There is, however, another aspect to the use of aluminium in pipe lines and storage tanks and that is that the high reflectivity of the metal assists in maintaining an even temperature inside the container and, in particular, it is most efficient in minimizing evaporation by the heat of the sun. It is important to note that aluminium surfaces do not readily dull and, because of this, considerable and extending use of aluminium is being made for the external treatment of tanks and pipe lines. Again, there is no set rule to the way in which aluminium is employed, and sheet, foil, sprayed metal coatings and films of aluminium paint are all valuable and effective treatments, each with its own particular sphere of usefulness. Sheet metal and foil are similar in reflection characteristics and are more efficient than either metallized or paint coatings. If paint coatings are employed, the newer paste aluminium products possess a higher reflectivity than paints prepared in the old way by mixing dry aluminium pigment into an oily medium. If powder is employed, the coarser grades may often give a higher reflectivity than the finer paint grades. Metallized coatings are more dull, but they are also more permanent than paint coatings when applied in reasonable thickness. The condition of the top of a storage tank has the greatest influence on evaporation losses, and it is not uncommon to find a metal foil covering applied to the outside of the roof whilst the sides are painted.

The efficiency of aluminium in reducing evaporation losses and the relative efficiencies of aluminium foil and paint become obvious from the results of tests on three 80,000 barrel tanks in Texas. In these tanks, the evaporation losses over a period of 90 days were:—

|                                                                             |              |
|-----------------------------------------------------------------------------|--------------|
| Tank 1.—Unpainted                                                           | 375 barrels  |
| Tank 2.—Sides and roof coated with aluminium paint                          | 240 barrels. |
| Tank 3.—Sides coated with aluminium paint, roof covered with aluminium foil | 81 barrels.  |

The U.S. Bureau of Mines Technical Paper No. 505 details the results of evaporation loss measurements in five horizontal tanks situated

at bulk-storage stations. The tanks measured 20 ft. long by 10 ft. diameter and measurements were made over the period May 29 to October 15, 1930, a pressure-relief figure of 202 being maintained in all cases. The results are given in Table 20:—

Table 20.—Effect of External Treatment on Tank Evaporation Losses

| Tank | External treatment              | Evaporation losses |      |
|------|---------------------------------|--------------------|------|
|      |                                 | Gallons            | %    |
| A    | White paint + insulated housing | 112                | 1.40 |
| B    | Covered with aluminium foil ..  | 170                | 2.12 |
| C    | Red paint .. .. .               | 284                | 3.54 |
| D    | 2 coats aluminium paint .. ..   | 187                | 2.34 |

In considering the results shown in this table, it must not be overlooked that the white paint on Tank A was used in conjunction with an insulated housing. Had the experiments been conducted over a longer period of time, the results might well have been more favourable to Tanks B and D, as aluminium foil and paint dirty and dull less rapidly than white paint, and there is every reason to believe that aluminium foil applied over the insulation of Tank A would have provided an even power figure for evaporation losses.

Reverting to the subject of the chemical corrosion of storage tanks, a report on tests made on all-aluminium and on composite steel and aluminium storage tanks in Texas makes interesting reading. Two tanks of equal capacity and shape were produced, one being entirely of aluminium and its alloys, the other of composite construction with the top ring and deck of aluminium. After being in use for exactly one year, the tanks were opened, cleaned and inspected by officials representing the owners, the Bureau of Mines and the producers of the metal. They were reported to be in excellent condition and practically free from corrosion due to oil and water.

The all-aluminium tank had been used for "bad oil" direct from the well, carrying over 30 per cent. of water, and the tank, therefore, contained some 8 ins. to 10 ins. of brine on the bottom at all times. At the water level of the lower ring some discoloration was apparent, which was so faint that it could not be detected by touch and there was no roughened surface. The metal in the oil phase was free from discoloration and as smooth and bright as when rolled. This statement also included rafters, channels, ladders and bolts. New steel bottoms in an adjoining tank installed at the same time as the aluminium tank and handling the same oil, developed leaks in six months, whereas the aluminium bottom was not pitted halfway through after a period of 12 months. The composite aluminium-steel tank was used for the treated oil, which did not contain more than 1½ per cent. of water and was practically free from hydrogen sulphide. Both the steel and aluminium were in good condition, substantiating the theory that the use of aluminium in the vapour phase will protect the steel below by preventing the formation of sulphide scale.

The results of such a test, when summed up, indicate that in this particular type of plant an aluminium tank will have a long and useful life with a minimum of upkeep, and that it can more than justify its additional first cost. No evidence of galvanic action was discovered between the various aluminium alloys used, or between the aluminium and steel in the composite tank.

In another case, where particularly sour oil was stored in a tank with a floating roof, protection was applied to the latter by metal spray, and a number of metals were first applied to different portions of the roof for comparison purposes. It was found that zinc and cadmium gave very little protection, whereas aluminium was highly effective. Slightly better protection was afforded by a thick coating of lead, but the weight of such a thick coating of dense metal created a problem of its own.

#### *Distillation*

By means of distillation, crude petroleum oils are separated into fractions such as light petroleum, heavy benzene, light and heavy kerosene and gas oil. Aluminium is unattacked by all these materials and by the sulphurous compounds present in the oil and which cause serious corrosion of ferrous metals employed in distillation apparatus. Moreover, the good thermal conductivity of aluminium, its lightness and the fact that it does not discolour the product commend it for use in most distillation plants. Unfortunately, the temperatures employed in the fractionation of petroleum oils are too high to allow the use of massive aluminium except in certain less important accessories, such as bubble caps, and in the lower temperature side of the plant. Thus, heating worms placed in a furnace, the temperature of which may be anything up to 220 degrees C., are used for passing the distillate to rectifying columns, the light metal being employed mainly to ensure the absence of discoloration in the product.

Aluminium as a material of construction for bubble caps has been an outstanding success in reducing upkeep costs. In one case, measurement of the relative corrodibility of aluminium and cast-iron bubble caps after being in service 16,217 hours showed that the cast-iron caps corroded 10.8 times as fast as those in aluminium.

A number of heat exchangers fitted to cracking as well as distillation apparatus have been made of aluminium.

In the form of a sprayed-on coating, however, aluminium is employed as a protection for the steelwork of fractionating columns, both inside and out, even for the high temperature parts of the plant. Because of the importance of this aspect of the subject, it will be dealt with in further detail later.

#### *Filtration and Sweating*

After distillation, the products are cooled in aluminium heat exchangers and then stored for a sufficient time to allow the entrapped oil to separate from the paraffin, after which the material is filtered through a metal gauze. Aluminium gauze may be used with advantage on account of its lightness and non-discolouring properties. The final product is eventually taken to the main storage tanks, often passing through inter-

mediate storage tanks on the way. Thus, the Anglo-Iranian Oil Co. installed 26 tanks, each of 2,000-gallon capacity, between the refineries and the stores of one installation in 1935. Aluminium covers were employed for all the man-holes and all-aluminium construction was employed for one tank, so that the behaviour of the metal in comparison with iron and steel could be observed over a number of years.

The finished oil, although ready for the many and varied uses to which petroleum products are put, is still not without corrosive effect on ferrous metals, and the arguments applied to the use of aluminium in storage tanks for crude oil apply, although with diminished force, to containers for the storage of the refined product. The external treatment of the tanks to increase heat reflectivity and so to reduce evaporation losses is as important as ever, and even where no use of aluminium is made inside the storage tanks, it is still quite customary to paint the external surface with aluminium paint, and occasionally, to cover the top with aluminium foil.

In the final handling and transport of the oil, aluminium does not play such a prominent part. An aluminium dock hose was made by the California Oil Tool Co. in 1938. It was built up from aluminium-alloy tubing in two diameters of 4 ins. and 6 ins., and made into self-contained 50-ft. lengths. Each length contained five joints and 12 swivel points, so that maximum flexibility could be obtained. The hose was capable of handling petroleum products under pressures up to 500 lb. per sq. in. In comparison with canvas hose, the strength and non-leaking characteristics of the light-metal hose were much appreciated, whilst the absence of danger through sparking and the light weight of the equipment placed it far ahead of flexible steel hose for safety and ease of handling. The weight of one 50-ft. length of 6-in. hose, complete with fittings and flanged end was only 490 lb., which meant that it could be handled by dock labour and did not require the use of a crane.

In containers for rail and water transport, massive aluminium is not often employed. There is, however, a significant move throughout the transport world towards the increasing use of aluminium in the construction of transport equipment of all kinds, not so much from the corrosion point of view but because it is recognized that the decrease in deadweight obtained, though demanding an increased initial capital outlay, is an eventual economy of considerable magnitude.

At the moment aluminium paint is much used on such transportation equipment to protect the steel sheeting from atmospheric corrosion and to provide some measure of heat insulation. However, there is every sign that future developments may include the use of sheet aluminium for constructional purposes and crumpled aluminium foil for efficient thermal insulation.

For controlling the flow of petroleum products along pipe lines or from containers, a number of special types of valve have been constructed in aluminium. One type, made in Pittsburgh in 1938, was a cylindrical design operated by a handwheel which turned a screwed rod in the valve bonnet. It was made in a number of sizes between  $\frac{1}{2}$  in. and 3 ins.

Another design, consisting of a light-alloy body lined with Barronia metal and fitted with a Barronia metal tapered cock has been referred to and illustrated earlier in this article.

Aluminium valves and valve seats may be employed on general service reciprocating pumps handling cold oil. Satisfactory service is obtained even in the handling of sour oils which normally cause serious corrosion of steel valves and valve seats. Disc-type aluminium valves are satisfactory for reciprocating reflex pumps handling light oil fractions at temperatures up to 200 degrees F. These valves may, therefore, be employed in contact with hot oil from the distillation or cracking plant.

Aluminium is regularly employed for the construction of conservation or breather valves, being used for the valves, valve stems, seats and guides. The main advantage of aluminium for this purpose is the absence of sparking which, although not probable with steel valves, is always a possibility and, if it does occur, it generally causes a most serious accident. For this reason aluminium is generally the material chosen for the construction of flame arresters attached to the breather outlets of oil storage tanks. They consist principally of alternate layers of flat and corrugated aluminium sheet and stand up very well to corrosion both by the atmosphere and by the vapours from the contents of the tanks.

The "Varec" Vapour Recovery Systems Co. make considerable use of aluminium in the construction of vents, flame arresters and pressure valves on storage tanks; gauges of all kinds; swing and swivel joints on hoses and pipe lines; and hand holes, manholes and covers for equipment of all types. Apart from the resistance of the metal to corrosion, and its freedom from sparking, this concern note that it is not excessively brittle at high temperatures and does not fly into pieces if struck by a stream of water or foam from a fire extinguisher when heated to 400-500 degrees F. by a conflagration. Apparently, this behaviour is not uncommon with valves and other components in alternative metals, and it adds materially to the difficulty of extinguishing a conflagration.

#### *Metallizing in the Oil Industry*

The undoubted advantages of aluminium to the oil industry have led to extensive experiments on the use of sprayed light-metal coatings on steel structures. In this form, some of the advantages of aluminium, notably a large measure of the corrosion resistance, absence of contamination and high reflectivity for light and heat, which are characteristic of the massive metal, are imparted to the steel structure without the heavier initial capital outlay of an all-aluminium structure. This is not to say that metallizing will necessarily give the same satisfactory performance as massive aluminium, but it has the advantage that it is a treatment which can be applied to existing steel structures and that where the expense of massive aluminium is viewed with some timidity or where the life of the metal under the conditions appertaining is an unknown quantity, aluminizing often provides a half-way stage both in price and in performance. To these advantages must be added the considerable degree of resistance to high temperature oxidation which sprayed

aluminium coatings impart to steel apparatus.

It is not surprising, therefore, to find a considerable utilization of aluminized steel in the oil industry. Dow gauge pots, valves and dephlegmeters are commonly sprayed with aluminium. So are many of the component parts of Dow hot oil pumps, and it has been found that this treatment has greatly improved the wearing properties of the valve parts. Formerly heavy corrosion was experienced, but this was almost completely eliminated by the application of a heavy coat of aluminium. The aluminization of the dome of a flash tower gave rise to considerable satisfaction. It was also applied to the interior of a Dublin coke chamber and both the coating and the underlying steel were found to be in good condition after nine months of service, adequate protection having been given against chemical attack, chiefly by hydrogen sulphide, and abrasion caused by the movement of coke.

In one installation considerable trouble was experienced through high temperature oxidation of the tubes in the water-cooled walls of boilers in the power plant. This was entirely eliminated by the application of a coat of aluminium 0.013 in. thick. Finally, in 1935, the Asiatic Petroleum Co. aluminized the entire interior of a petrol fractionating column for use in the Dutch West Indies. The column measured 94 ft. long by 13 ft. diameter and altogether 6,000 sq. ft. of surface were first grit blasted and then sprayed with aluminium to a thickness of 0.018 in., using 1,300 lb. of light metal. This is a most interesting experiment since the corrosion resistance and the absence of contamination afforded by the use of aluminium coatings would be very welcome, but the high temperatures involved have hitherto prohibited the use of the metal in massive form except for minor components. It is hoped that information will be made available to show how successful sprayed-on coatings of aluminium have been in this particular application.

#### *Aluminium in the Salt Industry*

Neither crude nor refined salt can be manipulated or transported in contact with the majority of metals, not only because it is extremely corrosive but also because traces of metal, if picked up, will spoil the colour of the dry salt. Wood is used a great deal in contact with salt, but has the disadvantage that any grains of salt left on the wood, or which find their way into the grain of the wood, absorb moisture from the air and dissolve in it so that the salt gradually permeates the wood.

Aluminium, on the other hand, possesses remarkable resistance to corrosion both by the salt crystals and by the atmosphere when the metal is not in contact with the salt. At the same time, any corrosion products which do form do not discolour the salt and are, of course, completely non-poisonous. Grains of salt cannot work into the metal as they do in wood and the smooth aluminium surface is easily cleaned and maintained in a dry and thoroughly hygienic condition.

For these reasons aluminium is employed to a considerable extent in the salt industry in operations where the metal runs no risk of contact with aqueous salt solutions which are corrosive to aluminium. In the mining and

earlier refining operations, the metal finds application in such auxiliaries as shovels, rakes and drain chutes, but its major application is in salt drying plant. The following, which is a description of a "Sirocco"-type salt-drying plant, may be taken as typical of such equipment.

The salt, which may contain 5-10 per cent. moisture, is supplied to the dryer on a rubber belt conveyor running on cast alpac rollers. The salt is deposited from the conveyor belt into an almasilium (0.8 per cent. Si, 0.8 per cent. Mg, remainder Al) hopper of riveted construction, and is then supplied at a uniform rate to the buckets of a vertical elevator. The buckets are in light metal and are made in one piece by deep drawing of almasilium sheet. The elevator operates in a wooden shaft lined on the inside with thin aluminium sheeting. From the top of the elevator the salt drops down a short chute, made of riveted aluminium, into the top of the drying tower, passing, en route, through a special distributor which, at the same time, prevents the ingress of cold air. The chute is built up from riveted almasilium sheet, and the parts of the distributor which come into contact with the salt are also of aluminium. The drying tower has an outer shell made of almasilium sheets riveted together and suitably strengthened by extruded sections in the same alloy.

The drying mechanism consists of seven almasilium plates arranged one above the other, and, over them, hot air is circulated on the counter-current principle by the use of suitable baffles. The salt is gradually raked from one plate to the other by rakes carried by rotating arms which are attached to a vertical shaft passing up the centre of the tower. The various baffle plates which guide the salt are made of almasilium sheet. The central shaft is made of special corrosion-resistant steel and is protected from contact with the salt by an outer tube of almasilium. The dried salt has a moisture content of 0.2-0.3 per cent. and is removed from the bottom of the drying tower by means of a screw conveyor, the parts of which may be cast in an aluminium alloy of low copper content and heat treated to obtain satisfactory wear resistance. The dry salt is then lifted up by a bucket elevator, similar to the one previously described, and deposited through a vibrating sieve into a storage bunker. The vibrating sieve is built up from almasilium extruded sections and aluminium gauze. The storage bunker is built up from aluminium sheets riveted together and strengthened by extruded sections and the bottom of the bunker, through which the salt is removed, is an aluminium-silicon alloy casting.

The drying tower is fitted with a cyclone type of dust precipitator and an 8-meter high chimney, all of which are made entirely of almasilium.

Similar installations have been built for the drying of coarse-grained salt, which is much more abrasive, and also for drying potassium chloride, and in all cases the results have been very satisfactory.

Often, wooden containers for the bulk transport of table and industrial salts are lined with aluminium sheet of not less than 99.5 per cent. purity with the double object of making the

box salt-tight and of preventing the ingress of moisture. The same treatment is sometimes applied to wooden storage bunkers, and in both these cases aluminium is definitely superior to zinc, tin or galvanized iron, which are the metals most commonly employed for lining wooden containers.

#### *Aluminium in the Soap Industry*

In the soap industry, aluminium is employed in two roles only, but nevertheless, quite important roles. The first is in the construction of storage tanks for the fatty acids which constitute the principal raw material used in the manufacture of soap. The other role occurs at the extreme far end of the processing scale and takes the form of wrappings for the finished product. In both these roles aluminium has been chosen because it exhibits a satisfactory resistance to corrosion by the materials in contact with it and because what corrosion does inevitably occur, either through reaction with the soap or with the atmosphere, does not result in any discoloration or spoilage of the material. In addition, aluminium, by its inherent characteristics, makes an attractive package and adds less to weight than would, say, lead foil.

Aluminium is remarkably resistant to the higher fatty acids such as stearic, palmitic, oleic and margaric acids, and consequently, aluminium is used for stills, condenser coils, filter presses, drying and storage vats, etc., employed in their production. In the handling of these acids aluminium vessels not only have the advantage of avoiding discoloration of the product, such as is encountered when other metals are used, but, if the solid acids, such as stearic, are solidified in suitably shaped aluminium vessels, they do not adhere to it and can be removed without difficulty. For high temperature work, aluminium-silicon alloys are said to be more resistant to attack by these acids than is aluminium itself. Completely anhydrous acids may react violently with aluminium, but only traces of water will completely prevent the reaction and, as completely water-free acids are not met with in industry, this hazard may be eliminated from practical consideration.

The tanks in which the fatty acids are stored for use in the industry may reach large proportions. The Persil works near Basle, for instance, have an aluminium tank 7.5 metres in diameter and 7.2 metres high, with a capacity of 284,000 litres, while some years before the war four fatty acid storage tanks were made in France for a Belgian concern, each measuring 19 ft. in diameter and 29 ft. 6 ins. high. Such tanks are practically always made by autogenous welding of aluminium alloy sheet, which gives a leak-proof construction of high strength, rigidity and corrosion resistance. Frequently they contain heating systems, relying on steam circulating through coils of aluminium piping to fuse low-melting fatty acids. Aluminium pipes then take the molten acid from the storage tanks into the works. The value of the thermal characteristics of the light alloys in heat exchange equipment has previously been commented upon.

The Persil tank was erected about the year 1934 by the autogenous welding of aluminium sheets. The latter varied in thickness from top to bottom of the container, being 5 mm. thick

at the top and 12 mm. thick at the bottom, thus effecting maximum economy of materials. It stood on a concrete base, contact between the metal and alkali in the cement being prevented by a layer of bitumen. A lid was fitted, constructed of aluminium sheets on a framework of anticorodal extruded "T" sections. The total weight of aluminium employed in the complete tank was 5,520 kilos.

The Belgian tanks were also made by the autogenous welding of aluminium sheets. The metal employed was of 99.5 per cent. purity, and the thickness of the sheets varied from 13 mm. at the top of the tank to 15 mm. at the bottom. Steel angle stiffeners were attached at the top, and the tanks were covered with dome-shaped lids of aluminium sheet, assembled by riveting. The tanks stood on a bitumen insulating layer on a concrete foundation and contained two separate systems of steam pipes in aluminium, designed to melt the fatty acid and to maintain it at a temperature of 70 degrees C. Aluminium pipes were installed to convey the molten fatty acids from the tanks to the works.

In the intermediate operations involved in the manufacture of soaps and soap products, strong alkalis are mostly present, which render the use of aluminium impossible.

For the packaging of the final product, aluminium may be employed in a number of forms. Mostly it is used in the form of foil wrapping for shaving sticks and tablets of toilet soap. Impact extruded containers of aluminium are employed for the packaging of shaving creams. An innovation of the post-war period is likely to be the use of deep-drawn or impact-extruded cans for holding shaving sticks. Small numbers of such containers were on the market before the war and were far in advance of the normal tinplate containers which rusted almost before they left the shop, whilst they had the advantage over plastic cases in not being fragile or easily damaged.

Aluminium is not unaffected by soaps and soap products, but corrosion is not so severe as with iron and the corrosion product is not so unsightly as iron rust, whilst attack can, for all practical purposes, be prevented either by lacquering or, preferably, by the addition of a suitable inhibitor to the soap. Tooth pastes have a similar action to soap on aluminium and the practice of making inhibitor additions to tooth pastes destined to be packaged in aluminium collapsible containers is now widespread, and, as everyone knows from personal experience, as such containers are part of our daily life, the result is quite satisfactory.

#### *Aluminium in Sulphur Mining*

The most important worked deposits of sulphur are in Sicily and in America, in the Southern States of Louisiana and Texas. In Sicily, the native sulphur occurs in outcrops or near the surface and it is dug by normal methods of outcrop or shallow mining. The material thus obtained, containing about 15-25 per cent. sulphur, is stacked in lumps in brick kilns built on sloping hillsides and covered with powdered ore. The ore is kindled at the top and sets fire to some of the lump ore. The heat generated by the combustion of about 30 per cent. of the sulphur serves to melt the rest which flows off into wooden moulds and is then exported for purification, mostly by distillation.

Aluminium does not enter into these mining and refining operations.

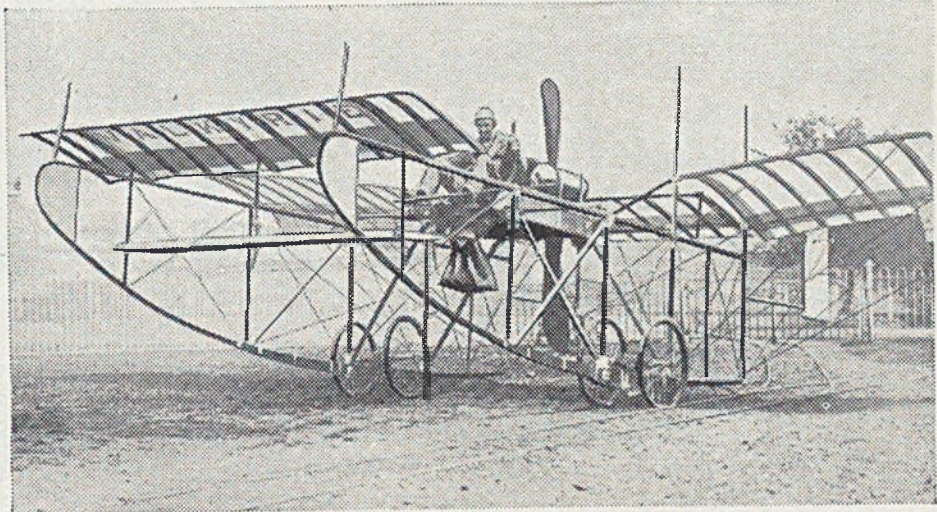
In America, however, the sulphur deposits occur deep down below clay, quicksand and rock, and a totally different method of mining is practised which yields a pure product not requiring refining. A boring is made to the deposit and four concentric pipes are sunk. Superheated water at 155 degrees C. is forced down the annular spaces between the outer three pipes, which fuses the sulphur deposit. Compressed air is then forced down the centre pipe and this forces an emulsion of molten sulphur and air bubbles up to the surface through the remaining annular space, that is, between the centre pipe and the next concentric tube. This emulsion is taken to a large wooden vat where sulphur of 99.5 per cent. purity solidifies and is ready for immediate use.

In recent years it has been found possible, in some cases, to use only two concentric pipes, steam and superheated water being pumped down through the annular space between the pipes and molten sulphur coming up the centre.

Although the sulphur obtained in this way is so pure, the equipment is exposed to considerable corrosion dangers by reaction with the molten sulphur, hydrogen sulphide and organic sulphides, all at elevated temperature. The resultant corrosion of plant and discoloration of the product, which occurs when ferrous and cuprous metals are employed, has led to the adoption of aluminium for parts of the apparatus coming into contact with these corrosive materials, because of the known high resistance of aluminium to sulphur, hydrogen sulphide and organic sulphides. In this way the exceptionally high purity of the product is maintained. Thus, aluminium has been employed for certain of the concentric pipes, the inner two where four concentric pipes are employed, or just the inner one where only two pipes are used. The outer pipe is always made of iron, partly for cheapness, but mostly because it suffers considerable abrasive contact with earth, sand and rock and, because of the disposition of the water and compressed air streams, an aluminium outer tube would show no advantage beyond reduced weight.

The double concentric tube has been employed mostly in Texas coastal fields, and ordinary screw joints have proved perfectly satisfactory when treated with a suitable anti-seize lubricant, e.g., a mixture of petrolatum and zinc.

The metal has also been employed to some extent in the transport and handling of molten and solid sulphur and for piping exposed to sulphur and sulphurous fumes. A light-alloy wheelbarrow has found wide use for the handling of sulphur. Not only does it ensure the maintenance of a high purity uncoloured product, but, being light in weight, it enables a greater useful load to be carried by one man without any increase in the energy consumed. The weight of a wheelbarrow is a source of wasted energy in the transport of whatever load the barrow is carrying, and a small saving in this weight results in a large decrease in the total energy consumed in using a wheelbarrow throughout the day. In the barrow referred to a reduction in weight of from 58 lb. down to 29 lb. has been effected by making the framework of extruded duralumin and the box in sheet duralinox.



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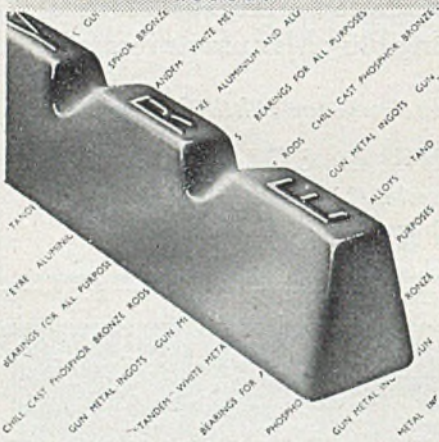
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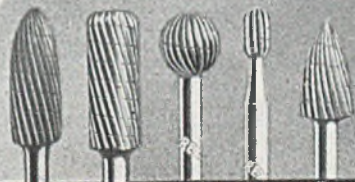
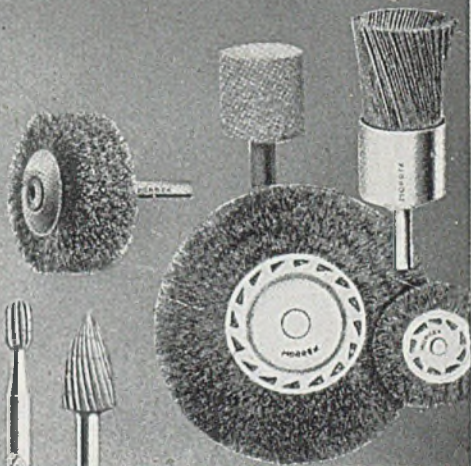
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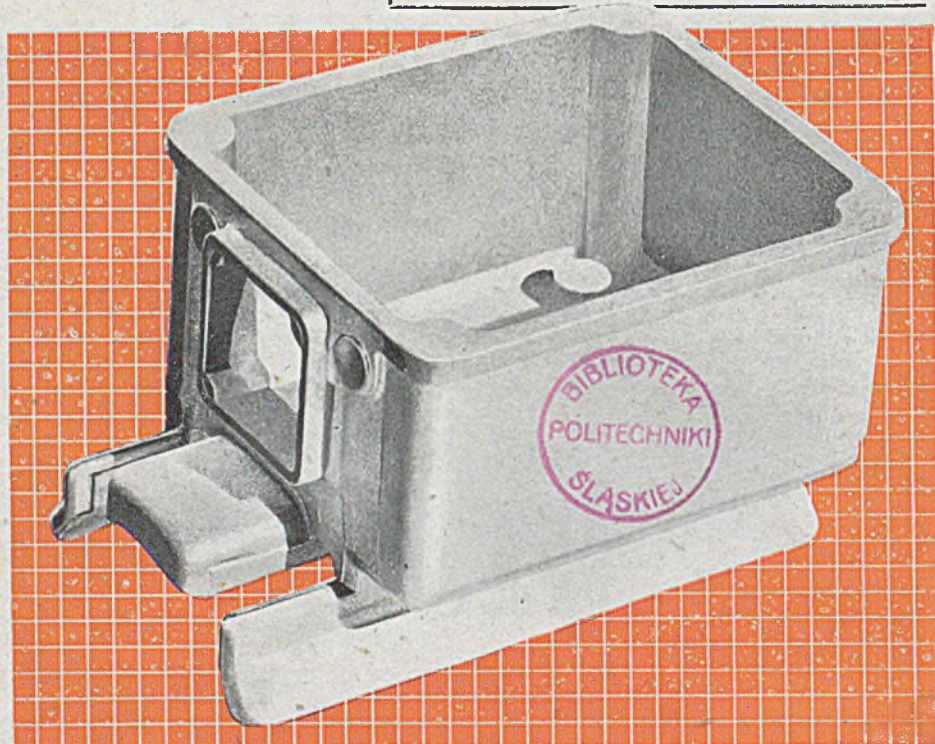
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