ABSTRACTS

DEPARTMENT OF ELECTRICAL COMMUNICATION ENGINEERING

1. ELECTRON TRANSIT TIME EFFECT ON NEGATIVE GRID OSCILLATORS. S. K. Chatterjee and B. V. Sreekantan, *Wireless Engineer*, February 1950.

Electron transit time effects on the output and efficiency of some triodes having different geometrical structures have been studied. The results indicate that for valves 833-A, 834, 304-B, the limit of oscillation is reached when the period of oscillation is nearly four times the total time of transit of the electrons from cathode to anode, whereas for valves 316-A, and 955, the limiting frequency is reached when the period of oscillation is nearly three times the total time of flight. The transit-time expression given by Gavin has been modified by taking into consideration the alternating voltages on the anode and grid and the negative bias. The wavelengths at which the efficiencies of valves drop by 10% and also down to 10%, have been found, and the results compared with the values obtained theoretically from the expression given by Gavin.

2. ELECTRICAL CONSTANTS OF SAND AT ULTRA-HIGH FREQUENCIES. S. K. Chatterjee, *Indian Journal of Physics*, Vol. 24, No. 4, 1950.

Electrical constants of dry and moist sand (up to 5% moisture content) have been measured over a frequency range of 300 mc/s to 500 mc/s. The dielectric constant, conductivity and loss tangent increase with increasing moisture content. The dielectric constant and conductivity of dry sand vary between 2·6 to 2·7 and $0{\cdot}26 \times 10^{8}$ e.s.u. to $1{\cdot}04 \times 10^{8}$ e.s.u. respectively over the frequency range in question. Loss tangent for dry sand varies from 64×10^{-3} to 153×10^{-3} over the same frequency range. The reflection coefficient for dry sand remains practically constant at 0·24 over 300 mc/s to 500 mc/s. But the phase change on reflection varies with frequency. The reflection coefficient increases from 0·24 to 0·35 at 500 mc/s for dry sand to 5·6% for moist sand. There occurs also a variation of phase change on reflection with different moisture content.

3. ABSORPTION AND REFLECTION OF U.H.F. WAVES (300–500 mc/s). S. K. Chatterjee and B. V. Sreekantan, *Indian Journal of Physics*, Vol. 23, No. 6, 1949.

The present paper deals with the absorption and reflection suffered by a plane electromagnetic wave (300–500 mc/s) while travelling a solution of a mixture of electrolytes simulating sea water. Experimental results indicate maximum absorption at 380 mc/s and very little variation of the reflection coefficient over the frequency range in question. It has also been observed that the dielectric constant and conductivity increase with increasing frequency of the incident wave.

4. ELECTRON TRANSIT TIME EFFECTS IN TRIODES AS NEGATIVE GRID OSCILLATORS. S. K. Chatterjee and B. V. Sreekantan, *Electrotechnics*, 1949.

Effect of electron transit time on the efficiency of several triodes used as negative grid oscillators under class 'C' condition has been studied. Limiting frequency of oscillation for each valve has been found.

5. ELECTRON TRANSIT TIME IN NEGATIVE GRID OSCILLATOR. S. K. Chatterjee and B. V. Sreekantan, *Indian Journal of Physics*, Vol. 23, No. 3, 1949.

Expressions for the time of flight of electrons between cathode to grid and grid to anode of a triode working as class C oscillator have been derived taking into account the effect of a.c. voltages on the plate and grid and also the grid bias. The expressions have been employed to calculate the transit time in the case of some tubes and certain interesting conclusions have been arrived at.

6. THE ELECTRICAL PROPERTIES OF SEA WATER AT ULTRA HIGH FREQUENCIES. S. K. Chatterjee and B. V. Sreekantan, *Electrotechnics*, 1949.

The paper presents a report of experimental investigation on the electrical properties of sea water over a frequency range of 300 mc/s to 500 mc/s. Frequency dependence of attenuation coefficient, absorption index, reflection coefficient, refractive index and conductivity has been studied. The result indicates very little variation of reflection coefficient over the frequency range. The conductivity has been found to increase with increasing frequency. Variation of absorption index with frequency indicates peak absorption at 380 mc/s.

7. DIELECTRIC CONSTANTS OF SOME SOLID INSULATING MATERIALS AT ULTRA SHORT WAVES. S. K. Chatterjee and Miss Rajeswari, *Indian Journal of Physics*, Vol. 22, Part IV, 1948.

The dielectric constants of several insulating materials in the form of thin slabs have been measured by the Lecher wire method over a wavelength range of 140 cm. to 57·7 cm. The dielectric constants in the case of materials under investigation have been found to vary with wavelength. In the case of solid paraffin, the dielectric constants have been found to increase with wavelengths becoming shorter. In other cases dielectric constants show a decreasing tendency with wavelength decreasing.

8. EFFECT OF MOISTURE CONTENT ON THE DILECTRIC PROPERTIES OF SOME SOLID INSULATING MATERIALS AT ULTRA HIGH FREQUENCIES. S. K. Chatterjee, *Indian Journal of Physics*, Vol. 22, Part VI, 1948.

The variations of dielectric constant and power factor of ebonite and fibre with different moisture contents have been studied at frequencies of 214 mc/s to 750 mc/s. The results show an increase of dielectric constant with increasing moisture content. The rate of increase of power factor with increasing moisture content is much greater at lower frequencies. Loss factor, temperature coefficient of dielectric constant and power lost in the dielectrics at several frequencies for different percentages of moisture content have been calculated.

9. ABSORPTION OF ULTRA HIGH FREQUENCY WAVES IN SALT SOLUTIONS. S. K. Chatterjee and B. V. Sreekantan, *Indian Journal of Physics*, Vol. 22, No. 12, 1948.

The absorption of ultra high frequency electromagnetic waves by aqueous solutions of $MgCl_2$, $CuSO_4$, and KCl has been experimentally studied. The results indicate two absorption peaks for copper sulphate solution but one absorption peak for magnesium chloride and potassium chloride solutions over the frequency range 300 to 500 mc s. Absorption maxima shift towards higher concentration for higher frequencies for all the solutions. The average values for the product of normality at which maximum absorption takes place and corresponding wave length are 11·96, 8·648 and 15·96 for $MgCl_2$, $CuSO_4$ and KCl respectively. The observed relaxation time shows values lower than the theoretical values for all the solutions. Radius of rotor calculated from the observed values of relaxation time for the solutions indicate that the absorption is due to the ionic atmosphere rotating as a whole under high frequency stress.

10. DIELECTRIC PROPERTIES OF SOLID INSULATING MATERIALS AT 750 mc/s. S. K. Chatterjee, *Indian Journal of Physics*, Vol. 22, Part IV, 1948.

The dielectric constants and power factors of solid insulating materials like mica, mycalex, plexi-glass, etc., have been measured at 750 mc/s. The loss factors and power dissipated in watts in the materials have also been calculated from observed results. A resonant line oscillator, having tuned concentric lines in the filament circuit, has been constructed for the purpose. The detector, which is also of the resonant line type, has been constructed for voltage measurement.

11. ABSORPTION OF ULTRA HIGH FREQUENCY WAVES IN SALT SOLUTIONS. S. K. Chatterjee and B. V. Sreekantan, *Indian Journal of Physics*, Vol. 22, Part VII, 1948.

The percentage of absorption and reflection suffered by u.h.f. waves (300–480 mc/s), in aqueous solutions of magnesium sulphate and calcium chloride have been determined. The absorption index, attenuation coefficients and reflexion coefficients for various frequencies at different concentrations of the solutions have been calculated. Experimental data have been utilised to calculate dielectric constant, loss tangent and absorption conductivity of the solutions at different frequencies and concentrations. The values of molar conductivity for magnesium sulphate have been calculated. The values of relaxation time obtained from experimental data have been compared with those calculated theoretically. The reflection coefficient shows very little variation with concentration and frequency. The molar conductivity increases with frequency over the range in question.

12. ABSORPTION OF U.H.F. WAVES IN SALT SOLUTIONS. S. K. Chatterjee and B. V. Sreekantan, *Indian Journal of Physics*, Vol. 22, Part V, 1948.

The percentages of absorption of u.h.f. waves (300–500 mc/s) in aqueous solution of sodium chloride for different concentrations have been measured by optical method. The attenuation coefficients and hence absorption indices have been calculated for different frequencies. The values of reflexion coefficients at different frequencies have also been calculated. The values of ionic relaxation time as obtained experimentally for different concentrations of the solution have been compared with the values calculated from Debye-Falkenhagen theory. The values of dielectric constant and loss tangent, as deduced from experimental results, have been compared with those calculated theoretically from the Debye-Falkenhagen theory. The values of dipole conductivity and molar conductivity have been calculated from experimental results and their variation with frequency studied. It has been found that the position of maximum absorption shifts towards higher concentration for higher frequencies. The product of wavelength corresponding to maximum absorption and the normality of the solution expressed in gm. equivalent per litre has been found to be 16·64, a constant.

13. APPLICATION OF TUBE 833-A AS ULTRA HIGH FREQUENCY OSCILLATOR. S. K. Chatterjee and B. V. Sreekantan, *Electrotechnics*, No. 20, 1948.

The tube 833-A has been used as a resonant line oscillator to generate frequencies upto 210 mc/s. A point-to-point analysis of the oscillator has been done for three typical operating conditions and only one of them has been reported in Table I with a view to furnish ready performance data for u.h.f. operation of the tube. The plate dissipation of the tube has been measured under oscillatory and non-oscillatory conditions by means of a thermocouple prepared for the purpose. The available r.f. output, plate and overall efficiencies have been computed and their variations studied over a frequency range of 26·5 mc/s to 210 mc/s. The total electron transit time as calculated from grid-cathode and grid anode spacings and amplification factor of the tube are $0 \cdot 92 \times 10^{-9}$, $1 \cdot 208 \times 10^{-9}$ and $1 \cdot 445 \times 10^{-9}$, second at plate voltages of 2,100, 1,000 and 700 volts respectively. The variations of output, plate and overall efficiencies with different transit angles have also been investigated. The results indicate a sharp decay of efficiency after 60 mc/s and also after the transit angle attains a value of 30°. The limit of oscillations at plate voltages of 1,000 and 700 volts have been found to reach when the transit times become one-fourth, approximately, of the period of oscillation. The optimum wavelengths at different plate voltages for the efficiencies to be reduced to 10% of the maximum value have been theoretically calculated.

DEPARTMENT OF AERONAUTICAL ENGINEERING

1. PHOTO-ELASTIC INVESTIGATION OF STRESSES IN RAIL SECTIONS. G. Janaki Ram, *Quarterly Technical Bulletin*, Vol. IX, No. 98, July 1950. Issued by the Director, Civil Engineering, Railway Board.

This problem has been undertaken at the instance of the Railway Board, which wanted the stress distribution in two new rail sections designed by them. The rail sections to be investigated were a 50 lb. rail 4¾" high and an 80 lb. rail 6" high. The former has a vertical load of 5·25 tons 0·6" off centre and a lateral load of 5·5 tons 0·375" below the top of the rail and the latter a vertical load of 9·25 tons and a lateral load of 10 tons with exactly the same displacements as in the previous case. It was necessary to obtain stress patterns under direct load and lateral load separately and finally under combined loading for each rail. A two-dimensional analysis was to be made and later a three-dimensional analysis, if possible.

This problem was investigated as a plane stress problem although it was realised that this treatment has this serious drawback that the maximum values obtained directly from experiment cannot straightaway be taken as exact stresses for the reason that the experiment gives only the maximum stress values per inch thickness of rail, whereas the actual values wanted are for the rail section as a whole. This limitation, however, does not in any way alter the nature of the stress distribution in the rail. The experiments have been conducted with rail sections cut out of bakelite sheet of only ¼" thickness. It is quite obvious that a ¼" thick rail subjected to the specified loads would develop exceedingly high stresses, far greater than the ultimate. Hence the need for interpreting the experimental results on the basis of certain assumptions.

Further, it is quite obvious that a mere ¼" thick rail does not behave in the same way as if it were part of a long rail. The necessary longitudinal rigidity cannot be obtained in a ¼" thick rail. This immediately presents another difficulty. The experimental section would be subjected to simple bending under the lateral load. instead of being subjected to reversed bending as is actually the case on account of longitudinal rigidity. Such reversed bending gives a cumulative compressive stress in the top fillet towards the side load and not tension as in a rail with no longitudinal rigidity. Therefore, it becomes necessary for the head to be constrained in order to approximate to the actual conditions.

The results are, therefore, governed by these two methods of approach, one in the experimental part and the other in the computation of stresses. In the experimental part, conditions giving an infinite rigidity to the head have been obtained by appropriate constraint. Less rigidity would give rise to displacement of the head in the direction of the side load, with consequent reduction in fillet compressive stresses. It was, therefore, considered more desirable to obtain conservative values of compressive stress with infinite rigidity of the head than to obtain small stresses, assuming arbitrary side displacements, as the magnitude of the displacement is not known. It would be quite easy to plot the maximum compressive fillet stress against side deflection so that the actual compressive stress could be read off against a known deflection.

Experiments were conducted to obtain the maximum stress values in the fillets under the combined action of direct and side loads. The values of the stress in terms of the fringes and in tons per sq. in. per inch thickness of rail are given in Tables I and II respectively:

TABLE I

	Under top right fillet	Under top left fillet	Over bottom right fillet	Over bottom left fillet
6″ Section ..	3·6 f. comp.	1·6 f. tension	2 f. tension	3·9 f. comp.
4¾″ Section ..	3·75 f. comp.	2·3 f. tension	2·1 f. tension	3 f. comp.

TABLE II

	Under top right fillet	Under top left fillet	Over bottom right fillet	Over bottom left fillet
6″ Section ..	170 tons/sq. in.	75·5 tons/sq. in.	94·5 tons/sq. in.	184 tons/sq. in.
4¾″ Section ..	154 tons/sq. in.	94·5 tons/sq. in. tension	86·1 tons/sq. in, tension	123 tons/sq. in. comp.

From a study of Table II it can easily be seen that there is a rather high compressive stress above the bottom left fillet in the 6″ rail section. To obtain more or less similar stress distributions in both the rail sections it has been suggested that the bottom left fillet in the 6″ rail section be modified to a radius of 7/16″ from a radius of ⅜″.

Care has been taken to stress the fact that this two-dimensional analysis does not accurately predict the *exact values* of the maximum stresses but that it gives a fairly good picture of the nature of stress distributions in the rail sections. The only limitations to this experimental analysis have also been pointed as the infinite rigidity of the head and of the infinite rigidity of the foundation.

DEPARTMENT OF INTERNAL COMBUSTION ENGINEERING

1. The Cyclone Combustion Chamber and Gas Producer. H. A. Havemann, Dr.-Ing. (Brunswick), *Mechanical Engineer*, 1951, No. 2 issue of the Mechanical Engineering Society, Indian Institute of Science.

Summary

The cyclone combustion chamber is considered qualitatively with reference to the conditions in the vortex and the equilibrium conditions, and dynamics of motion of fuel particles, and the general advantages are outlined when compared to normal combustion apparatus. Reference is specially made to a cyclone chamber for burning pulverised fuel. The cyclone gas producer and its design are described and specific as well as general conclusions are drawn supporting the usefulness of application of cyclonic combustion apparatus to meet the conditions of fuel supply in India.

1. Introduction

The cyclone combustion chamber is a new development in the field of combustion apparatus mainly for Gas Turbines but also for steam boilers, and it can also be applied for gasification processes. Its main objective is to make possible the complete combustion of fuels of low or extremely low rate of combustion. If successful, it would thus make it possible to use fuels which could not be used for power generation so far, especially if combined with methods to remove residues from the combustion gases.

The cyclone combustion chamber provides means of maintaining for a sufficiently long time either droplets of heavy liquid fuel or particles of pulverised solid fuel in conditions favourable for evaporation and combustion. It provides for a rotating motion of the fuel particle until it has been reduced to very small size due to the process of the reaction and until the combustion is practically completed.

2. Working Principle

2.1. *Combustion in the Vortex*

Air and droplets are admitted tangentially and enter a vortex type of flow through its periphery and the combustion gases are extracted axially from the centre. A matter of concern is the right shape for the volute[4] to guarantee smooth transition of the fluid from the entry to the vortex proper.

Between periphery and centre of the vortex combustion takes place, which is started in a primary combustion stage situated in the tangential entry to the chamber proper, where the primary flame is stabilized. There, the fuel particles, either heavy liquid fuel droplets or pulverized fuel particles are wholly or partly ignited, and they complete their combustion in the vortex of the cyclone chamber as far as the mechanics of the vortex allow.

2.2. *Equilibrium Conditions and Dynamics of Motion for Fuel Particles*

At a particular radius within the vortex droplets are held there under the influence of the centrifugal force, acting towards the periphery, and the viscous drag, directed towards the centre. For equilibrium both forces are equal and droplets would rotate at constant radius, the so-called equilibrium radius, about the centre under the action of these two forces, with relative motion of the gas, if their size would be constant. Thus continuously fresh oxygen is supplied to the periphery of the fuel particle for speedy combustion by the relative motion of the gas with respect to the particle. No random turbulence is created to step up the rate of combustion as is the case in normal combustion chambers and pressure losses, consequently, should be small.

The shape of the walls of the cyclone chamber according to a recent development,[4] is such, that the equilibrium of the droplet is made stable. This means, that any deviation from the equilibrium radius causes forces which lead the droplet back to its equilibrium radius. The restraint thus exerted on the droplet can be varied and different shapes of the walls result from the choice of the so-called stability factors.

With the shape of the chambers thus defined, it can be shown that equilibrium conditions are offered to droplets of different sizes, at different radii and big droplets will find equilibrium conditions at the periphery, small droplets near the centre of the chamber. Thus the droplet in the course of its combustion approaches, in spirallic motion, the centre of the chamber.

Since the temperature and pressure of the gas in the vortex, and the density, shape, etc., of the droplets are changing,[5] the equilibrium conditions and thus the radial distribution of droplets become a fairly complex function of the radius and so is the shape of the walls to create pre-determined conditions for all phases of combustion.

Under the restraint of the forces acting on the droplet or particle, it will oscillate radially about its equilibrium radius. This motion results in an increase, rhythmically, of the relative velocity, of the gas with respect to the droplet.

2.3. *Flow of Gas in the Vortex*

Under constant outer conditions, such as mass flow, pressure and temperature of the air at entry to the chamber the conditions of flow in the vortex will be fairly stable. Due to the chemical reactions taking place a certain temperature and pressure distribution will result, and it is a matter of concern whether the radial equilibrium of the rotating body of fluid is stable. Fortunately in the case of a combustion chamber, equilibrium conditions of the gas are in most cases fulfilled but in the case of a gas producer, as will be shown later, this is not so.

Changes in the conditions at entry to the chamber, say under different running conditions of the power unit result in changes in the equilibrium of the fuel particles, but the chamber is not very sensitive to these alterations.

2.4. *Physical Processes in Cyclone Combustion*

It can be shown, that the chemical and the physical processes governing the rate of combustion are capable of being accelerated[6] in cyclone chambers to a large extent, and beyond the measure normally observed in combustion chambers.

The rate of combustion of a fuel particle is mainly governed by physical processes since at temperature levels encountered in the combustion space the rate of chemical process is by far quicker than that for physical processes. In the physical processes effecting combustion the rate of heat transfer is predominant and the quantity of heat transferred to the particle depends mainly on the flow conditions around the particle, *i.e.*, mainly the relative velocity of the gas with respect to the particle.[6]

3. General Advantages of Cyclone Combustion Chamber

From the considerations so far it follows that the cyclone combustion chamber has the following advantages compared with other combustion systems, in consequence of which combustion intensity related to the individual particle may be increased.

(*a*) All sides of the fuel particle are exposed to the flow of the oxygen carrier and therefore the limitations due to the transport of matter are greatly reduced and also fresh air is available over a considerable part of the combustion period, thus maintaining the velocity of the chemical fraction.

(*b*) The relative velocity between particle and air is more a matter of choice according to the knowledge available than is the case in conventional combustion chambers.

(*c*) The cyclone chamber provides sufficient time for drying solid fuel particles, which, if dry, move nearer to the combustion zone in the chamber, or might even be disintegrated for the liberation of gases, and for the combustion of fuels of normally very slow rates of combustion.

(*d*) The chamber can be run as slagging chamber for fuels of high ash content, and thus the cyclone is adaptable to gas turbine power plants, for powdered fuel.

(*e*) The swirl in the exit of the chamber can be used to separate any residual matter from the hot combustion gases.[7]

4. Design Forms of Cyclone Combustion Chamber

The normal form of the cyclone combustion chamber is characterized by the location of the primary system in the entrance duct to the chamber, fitted with conventional baffles and swirlers and a nozzle for injecting fuel. The air plus fuel passes through the periphery to the vortex proper and the burning zone to exhaust gases which are extracted axially from the centre. The primary zone can also be located axially and droplets or particles together with air are led radially outwards to the periphery of the vortex and from there to the vortex proper and finally to the outlet.

A design specially suited for powdered fuel is the following:

The wall of a cyclone combustion chamber showing the usual shape is surrounded by another outer wall, and through the jacket produced in this way air is drawn in order to cool the inner wall. The cooling air is admitted at the periphery of the cylindrical part of the jacket in nearly tangential direction and leaves the jacket near the axis of the chamber by means of a volute surrounding the aperture of the combustion chamber.

Due to the spirallic form of the flow with gradually decreasing cross-sectional area the pressure at outlet will be low and the velocity will be high. The temperature of the cooling air is increased and this increase could be considerable by introducing means to intensify the heat transfer from the wall to the cooling medium.

The outlet ducting of the cooling air is formed in such a way that it turns around the body of the combustion chamber in two rectangular bends, and the air enters tangentially, at roughly the same radius, another jacket situated on the other side of the combustion chamber, in opposition to the aperture.

Between outlet and entrance of this ducting, however, the ducting forms an ejector with dimensions so that at the point of the smallest cross-sectional area the static pressure in the air jet is just below the outer static pressure. There a very small amount of air from the atmosphere is drawn in. This air is loaded with powdered fuel (coal dust), transported there with an Archimedian Screw or other means.

After the ejector the fuel-laden hot air will enter, as mentioned above, a jacket between outer and inner wall of the cyclone combustion chamber. Within this jacket, due to spirallic flow with gradually increasing cross-sectional areas, the pressure of the air is increased—as is the case in the diffuser—to such an extent that at the radius at which the jacket terminates and opens towards the inside of the combustion chamber, the air pressure is only slightly above the pressure inside the combustion chamber. During the flow through this ' spirallic diffuser ' the temperature of the air is increased still further and means may be provided again to intensify the heat transfer from the inner wall to the cooling air. At the rim of the jacket therefore hot air and fuel particles are delivered into the region of the combustion chamber, where combustion takes place.

5. The Cyclone Gas Producer

The rate of increase of all processes involved in combustion makes the cyclone attractive for application to a gas producer, especially as the rate of gasification in normal gas producers is not sufficiently high and thus orthodox gas producers are bulky, especially if mass flows are large. The successful solution of the inherent problems would result in an arrangement allowing to use low grade fuels to be used say, for gas turbine power plants.

In general, the combustible gas is produced by the combustion of carbonaceous material in a deficient supply of combustion supporting fluid, say, of air.

The following suggestions for the application of the cyclone principle to gas producers are made with respect to general design possibilities including wall cooling and starting conditions.

5.1. *Principles of Design*

There exist two main possibilities of design:

(A) Oxidation and reduction are carried out in one cyclone chamber only, and

(B) Oxidation and reduction processes are carried out separately in two different cyclone chambers.

5.2. *Particulars of Design for One Chamber*

If the generation of producer gas is maintained in one cyclone chamber, the injection of fuel for the oxidation and reduction zones can be arranged at two different points or from one point only.

5.21. *Insertion of Fuel from Two Points*

Restricting to fuel injection at two different points, design possibilities may be considered with the assumption of two fuels available, *e.g.*, pulverised coal and heavy fuel oil.

5.211. *Fuel for Oxidation Zone : Coal*
Fuel for Reduction Zone : Heavy Fuel and
Fuel for Oxidational Zone : Coal
Fuel for Reduction Zone : Coal.

The insertion of the fuel into the oxidation zone is done as mentioned before, for reduction zone coal of smaller particle size must be used.

5.212. *Fuel for Oxidation Zone: Heavy Fuel*
Fuel for Reduction Zone : Coal and
Fuel for Oxidation Zone : Heavy Fuel
Fuel for Reduction Zone : Heavy Fuel.

Insertion of liquid fuels should make allowance of right distribution of sizes, or a suitable burner design should be adopted.

5.22. *Insertion of Fuel from One Point*
Insertion of Fuel in Tangential Entry and
Insertion of Fuel in the Axis.

Air is admitted to two volutes around the aperture of the gas producer and the opposite end. Both air streams pass in spirallic flow through the jackets, thus cooling the walls of the chamber proper. They meet at the outer circumference and, assisted by their nearly tangential movement and by suitably curved vanes, the air, now at higher temperature, enters the chamber, establishing normal cyclone flow pattern.

Fuel, heavy fuel or pulverized fuel or both, is admitted in the axis only. Big particles traversing the reduction zone will reach equilibrium conditions near the circumference of the chamber, and establish the oxidation zone there, small particles will stay nearer to the axis constituting the reduction zone.

It is to be expected that the big particles on traversing through the hot zones will ignite when they meet suitable conditions (oxygen near the circumference). Their presence in the reduction zone for a comparatively small time should not give rise to disturbances.

Starting could be done with liquid fuel from the centre, or with a special arrangement, say, a baffle system at the periphery of the outer casing with a special air entry, which is shut down after the starting period,

5.23. *General Remarks*

In all cases wall cooling could partly and additionally be carried out by water, which as soon as vapourized, could be inserted by its own vapour pressure into the zone of reaction.

The rate of heat transfer from any wall to be cooled, to the cooling medium can be increased by providing fins, which at the same time could be used for guiding the air flow in the required manner.

5.3. *Particulars of Design for Two Chambers*

Oxidation and reduction are carried out separately in two different cyclone chambers.

In general the design of this scheme seems to be rather difficult especially with respect to ducting and wall cooling. The simplest possibility is to arrange a volute at outlet of the oxidation cyclone, which leads to a tangential entry of the second, reducing cyclone. Cooling air of both cyclones should be used as primary air for the combustion cyclone.

If both cyclones are arranged to have a common axis air could enter the system axially. There it is divided into the cooling flow and a small amount of primary air. The cooling flow, on passing the wall of the oxidation chamber, reaches the periphery and from there is led to the outlet of the gas producer. There it is converted and flows backwards, cooling in turn the wall of the reduction cyclone, the ducting between the cyclones, and the other wall of the oxidation cyclone. At the last the air now hot, enters tangentially the combustion cyclone establishing there the known cyclone flow pattern. Vanes at the periphery may assist to direct the air-flow.

Fuel is admitted to the combustion cyclone from the axis (pulverized coal or heavy fuel). Another possibility is to inject pulverized fuel into the hot cooling air shortly before it enters the cyclone. Fuel injection in the axis could be used for starting.

The hot combustion gases enter the second cyclone tangentially. Vanes could again assist the flow. They could be cooled, together with the wall, parting the second cyclone from the first one by circulating water through them.

Similarly, the cooling water could enter the jacket axially, and could, in vapourised form, enter the gas flow through holes in the jacket or in the blades.

Instead of water, liquid fuel or air could be considered as cooling fluid.

In the second cyclone reduction takes place. Liquid as well as pulverized fuel seems to be possible and injection could be undertaken through the cooling passages for air at a suitable point of the wall of the reduction cyclone.

5.4. *Conclusion with Respect to Gas Producers*

The chemical process may decide whether the design with one or two chambers is to be preferred. Insertion of fuel in the axis of one chamber seems to be a very simple design and, on the other hand, two cyclones as described should provide an efficient possibility.

It may be stressed, that for fuel with high residual content gas cleaning can be applied to the producer gas only, and thus the resulting pressure drop affects only part of the mass flow. This point has considerable importance for gas turbine units.

The question of radial equilibrium in the vortex may, however, create some difficulties since unlike in the case of the combustion chamber the temperature is decreasing with decreasing radius, and thus instability of the vortex may result.

6. General Conclusions

The cyclone combustion chambers either for direct combustion or for gasification and secondary combustion provides, unlike any other system, means of utilising hitherto unused fuel resources and in view of the fuel position in this country efforts should be made to apply the principles of combustion apparatus as outlined to power generation either in combination with reciprocating engines or with rotary engines.

7. List of References

1. Lander, C. H. .. "Improvements in and relating to carrying out chemical and physical processes," British Patent, No. B. P. 33108.
2. Hurley, T. F. .. "Some factors affecting the design of a small combustion chamber for pulverized fuel," *The Institute of Fuel*, April 1931.
3. Darling, R. F. and Ellis, H. S. "The Annular Combustion Chamber, its present state of development and future prospects," *Power Jets Report.*
4. Havemann, H. A. .. Un-published work at N.G.T.E.
5. Nils Frössling Lund .. "The evaporation of falling drops," *Gerlands Beiträge zur Geophysik*, 1938, **2**, 170.
6. Grodzovsky Choukhanoff .. "The primary reactions of the combustion of carbon," *Fuel*, 1936, **15**, No. 11, 321.
7. Havemann, H. A. and Hahnemann, H. W. "The movements of particles in a gas swirl," *N. G. T. E Memorandum.*

2. CRITICAL COOLING. H. A. Havemann, DR.-ING. (Brunswick). *Mechanical Engineer*. October 1950, No. 1 of the Mechanical Engineering Society.

SUMMARY

After explaining the nature of the critical state reference is given to the peculiar properties of materials in the critical state and conclusions are drawn with respect to technical applications and further fundamental research.

CONTENTS

1. INTRODUCTION

In normal practice one is accustomed to define the state of a material as solid, liquid or gaseous and there is a clear conception about the vapour state which is passed in the transition between the liquid and the gaseous state.

With increasing pressure the respective specific volumes, *e.g.*, of water and steam, at the respective boiling temperatures will come closer and closer together until at the critical pressure p_{cr} there will be a direct transition from water to steam with the intermediate range deleted. This point is called the " critical point " or better. " critical state ".

Considering a gas to be liquefied it is necessary to cool it below its critical temperature as otherwise any pressure to which it may be subjected could not bring about to condense it into a liquid.

2. THE CRITICAL STATE OF A LIQUID

It can be seen that

$$\left(\frac{\delta p}{\delta v}\right)_T = 0 \text{ and } \left(\frac{\delta^2 p}{\delta v^2}\right)_T = 0 \qquad (1)$$

Furthermore

$$\left(\frac{\delta T}{\delta v}\right)_p = 0 \text{ and } \left(\frac{\delta^2 T}{\delta v^2}\right)_p = 0 \tag{2}$$

The specific heat for constant pressure C_p becomes infinite in the critical state, and so does the thermal expansion coefficient β according to the definition

$$\beta = \frac{1}{v}\left(\frac{\delta v}{\delta T}\right)_p. \tag{3}$$

The heat of evaporation is zero, and the surface tension tends towards zero at or slightly above the critical state. The viscosity is decreased as compared to the liquid state as the material is in a state between liquid and gaseous.

3. Consequences of Properties in the Critical State

From the peculiar properties of the fluid in the critical point or in its surroundings several conclusions can be drawn which show the way for possible technical applications especially in the field of heat transfer.[1]

Judging the tendency of the values governing the rate of convective heat transfer if the coolant gradually approaches the critical state it is seen that the thermal buoyancy is increased due to the increase in the thermal expansion coefficient whereas the viscosity is greatly diminished. At the same time unit mass of transported liquid carries a larger amount of heat due to the increased specific heat. Thus a liquid in, or near, its critical state is ideally suited for heat transfer by natural or free convection.

The correlation between quantities defining the rate of heat transferred is normally expressed in terms, as follows:

$$Nu = \frac{\alpha l}{k}, \; Gr = \frac{l^3 g \beta \theta}{r^2}, \; Pr = \frac{r}{a}, \tag{4}$$

where

α = Heat transfer coefficient.
l = Characteristic length.
k = Heat conductivity coefficient (thermal conductivity).
g = Acceleration of the gravitational field.
β = Thermal volume expansion coefficient.
θ = Temperature difference.
r = Kinematic viscosity.
a = Temperature conductivity (diffusivity ratio).
= $K/Cp\mu$.
μ = Density or specific weight.

The quantities governing the rate of natural convection show clearly positive changes near the critical state.

4. RESEARCHES IN HEAT TRANSFER NEAR THE CRITICAL STATE

Investigations have been carried out to find the rate of heat transfer by free convection, mostly for plates and tubes placed in different directions in the gravitational field of the earth but all refer only to the normal state of the heat transmitting medium.

One experiment, however, has been conducted which proves that the rate of heat transfer in the critical state is increased. A vertical O-like shaped ring of tubes was filled with liquid in the critical state, and heat was added at a point near the bottom and rejected near the top of the ring. Heat transferred was roughly 100 times of what would be transferred by water at 60° C. The material used was ammonia for which

$$P_{cr} = 111 \cdot 62 \text{ kg./cm.}^2, \quad t_{cr} = 132 \cdot 9° \text{ C.}, \quad V = 4.24.10^{-3} \text{ m}^3\text{/kg.}$$

5. PRACTICAL APPLICATION OF HEAT TRANSFER IN THE CRITICAL STATE

The conception of intensification of heat transfer by natural convection in the critical state as a whole thus is correct. Methods of critical cooling or heating would allow to diminish the heat transferring surfaces and cross sectional areas and thus reduce weight and space requirements, apart from purely intensifying the heat transfer. Pumps for revolving the liquid could be abandoned. The temperature of the wall material would be within the limits which can be covered by normal or good steels even if they are exposed to gases of very high temperatures. One disadvantage is the high pressure of the coolant or heating medium in the working state. The effectiveness of cooling is increased considerably if the strength of the gravitational field is increased, and thus critical cooling lends itself to applications in rotary machinery where high radial accelerations are met with.

The application of cooling has been suggested with the coolant in the critical state in the following form: The hollow drum of the turbine rotor contains a water jacket and the blades carry several radial bores leading near to the tip of the blade. The pressure inside the drum and the speed of the rotor can be arranged so that the critical pressure of water is reached near the tip of the bore. Those layers of coolant which are near the wall of the bore will be heated first and the thermal buoyant force will consequently carry them towards the axis of the drum, *i.e.*, towards the water jacket. In the centre of the bore the coolant is at lower temperature and thus a circuit of the coolant is set up which carries the coolant radially outwards in the core of the cylindrical column, and radially inwards at the periphery of the bore. It is, of course, necessary to provide for controls for the maintenance of a definite water and pressure level in the drum.

The introduction of critical cooling to combustion turbines provides a possibility to use steel of only limited temperature resistance and thus eliminates the limitation of the gas turbine with respect to thermal efficiency.

6. Experimental Proof for Technical Applications

Experiments in the field of rotary engines have been carried out on a model apparatus, and on a model turbine.

The model apparatus consists of a tube closed at the lower end, and opening towards a larger vessel. The tube is heated externally in analogy to the heat input to the cooling bores in the turbine blade. The heated test liquid rises and enters the vessel, again in analogy to the coolant entering the water jacket. On entering the boiler the liquid is cooled and thus flows down along the axis of the boiler and re-enters the tube axially. Inside the tube the cold liquid along the axis of the tube, is deflected upwards and heated again.

Results with the model apparatus have indicated that a large amount of heat is effectively transported. An experimental gas turbine was built with the cooling arrangement indicated and it worked successfully with a gas temperature of 1,200° C.

7. Conclusions

The rate of heat transferred by free convection in the critical state of the heat transferring medium is very high as compared with normal conditions of the medium.

Research work should be taken up in the matter especially as the method allows the use of materials of normal quality where otherwise high temperature resisting steel must be adopted. Here lies the importance for this country of the method described.