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Letter-report
Registered

Sir Charles Ellis, F.R.S.,
Westminster House,
7, Millbank,
London, S.W.1.
England.

Dear Sir Charles,

PROJECT ARIEL

In this letter we report on the result of the work carried out during the period from December 15, 1962, and January 25, 1963. The main effort has been concentrated on the preparation of some practical devices which we demonstrated on the occasion of your visit to Geneva on January 9. Besides we have started to gather quantitative data with respect to the heat required in order to obtain a sufficient temperature in tubes of different material and dimension.

The recent discussions in Southampton were of great value for drafting a concise programme for the coming research period, and we appreciate very much that Drs Felton and Hughes have contributed their considerable experience to that end. It was agreed that this programme would also serve as a reference scheme for future correspondence.

1. Study of Extraction Procedures

The tobacco extract used in our experiments was prepared in the following way: 30 g of tobacco (W 428) was treated with boiling water for three hours on the reflux. After filtration the extract was liophilized. The residue of the

extraction with water was treated for another three hours on the reflux with chloroform. After filtration, the solvent was evaporated on a water bath at 60°C. Both extracts were combined by means of water being added in such a proportion that there resulted a highly viscous product. The nicotine content of this product is about 5%.

We are now preparing extracts according to procedures (a), (b) and (c) as described in Dr Felton's letter to Dr Haselbach of 16th January 1963.

2. Choice of Additive

For the experiments carried out so far, only one type of inorganic additive has been tried, i.e. alumina. The product was of the type used as catalyst carrier with large internal surface area. It was ground in order to obtain a coarse powder which was then mixed with the above extract on a 1:1 weight ratio. The necessity for and possible beneficial effects of such inorganic additions have still to be carefully assessed, and we intend to examine products of different chemical nature as well as of different structure as determined by specific surface areas and porosity.

3. Study of Effect of Additive and Choice of Extract

So far no systematic experiments have been carried out to settle these questions. The experiments will be started in a short while.

4. Study of Conditions for Maximum Transfer

We expected that the heat required to attain the desired temperature within the central tube depends largely upon the material of the tube as well as upon the dimensions. Some preliminary experiments had therefore been carried out in order to get a rough idea about

the influence of thermal conductivity of the tube material, diameter and wall thickness of the tube as well as of the heat input upon the temperature on the inside of the tubes. These preliminary experiments gave us some valuable information for choosing the range of conditions to be selected for the experiments 4(ii), 4(iii) and 4(iv). Table 1 gives the physical characteristics for the different materials which have been chosen. The glass tube can be considered as representative for ceramic material as in fact its characteristics are very similar to those of porcelain.

Table 1

Material	Heat conductivity ($cal.cm^{-1}.s^{-1}.grad^{-1}$)	Specific heat ($cal.g^{-1}.grad^{-1}$)	Specific gravity ($g.cm^{-3}$)
aluminium	0.5	0.22	2.7
steel	0.1	0.11	7.8
glass	0.002	0.2	2.6
(porcelain)	(0.0025)	(0.26)	(2.4)

Table 2 shows the maximum temperatures measured within the tubes at fixed heat input of 8.25 Watts.

Table 2

Material	Diameter (mm)	Wall thickness (mm)	Maximum temperature(°C)	
			without extract	with extract
aluminium	4	0.01	250	215
aluminium	4	0.3	150	
steel	4	0.35	250	220
steel	3	0.2	280	
glass	4	0.8	330	

These measurements show that the heat conductivity greatly influences the temperature. Our practical devices which were demonstrated on 9th January were made with the steel tube with a diameter of 4 mm and required the relatively thick Boyard cigarettes (diameter 10 mm) for external heating. One may therefore expect that with tubes of lower heat conductivity, like pipeclay, the diameter of the external heating can be reduced to the conventional 8 mm. The temperatures measured when the tube contained some tobacco extract where about 30° lower than those for empty tubes.

Table 3 shows the maximum temperature within a steel tube of diameter of 4 mm at different values of heat input.

Table 3

Heat input (watts)	Maximum temperature (°C)
5.5	182
6.4	205
7.7	222
8.8	254
10	266
12	292

The experiments were carried out in such a way that the electric heater was moved over the tubes at smoking speed, and the temperatures measured with a fixed thermocouple were recorded with a strip chart recorder. As in the contemplated practical device, at least part of the central tube is covered by the envelope of heating tobacco during smoking, we have carried out an experiment in which the moving electric heater pushed a cigarette over the tube in front of itself. The temperatures measured in that case were hardly different from those obtained with the naked tubes.

The way in which the experiments are carried out permits the temperature to be plotted as a function of the distance of the electric heater from the thermocouple. These plots will be made for all experiments. Figure 1 shows two such plots, for an aluminium-tube and a steel-tube of almost the same dimensions respectively. As expected, the steel tube leeds to a much steeper temperature gradient than the aluminium tube. In the case of the steel tube, the temperature drops to half of the maximum value at a distance of about 20 mm from the heater, while for the aluminium-tube the temperature profile is less steep. This agrees very well with an experiment which we made in order to convince ourselves of the necessity of the central aerosol chamber even when oils (orange oil) are added. A steel tube was packed with tobacco to which 5 µl of orange oil was added. When smoked on the machine, the first six puffs did not contain any nicotine, puffs 7 plus 8 gave 0.3 mg, and puffs 9 plus 10, 0,1 mg. This means that nicotine was only delivered when the heater was within 20 to 30 mm of the end of the tube because only then was the temperature at the end of the tube sufficient for nicotine release. These experiments give us also some hints as to the critical size of the central tube in the case of device 1 of the patent application. In the case of the steel tube, the critical length would be around 20 mm. In the case of metals with better thermal conductivity it can be expected to be longer.

As regards the supply of ceramic tubes, we encounter difficulties in getting all the dimensions we wish. We hope very much that the Southampton laboratories can send us some pipeclay tubes made by extrusion. In the meantime we shall try to make some tubes ourselves by hand.

4(iv) Nicotine transfer in terms of heat input :

A series of experiments has been carried out with the extract described under 1, whereby the heat input was varied. We used the 4-mm diameter steel tubes which give a performance similar to that of the tubes made from aluminium foil. The extract mixed with alumina on a 1:1 ratio was sucked into the tubes and distributed as evenly as possible by rotating the tube.

In the future experiments we shall paint the extracts on aluminium foils before these are rolled up into tubes. In this way we shall be able to obtain better reproducible conditions.

Table 4 shows the results of the nicotine analysis.

Table 4

Heat input (watts)	Maximum temperature (°C)	Nicotine (mg)		
		before smoking	on filter	after smoking
~ 9	220	16.5	0.65	
~ 11	250	8.7	1.24	3.32
~ 14	300	9.5	1.31	0.34

These experiments show that with our extract we need rather high temperatures in order to obtain one to two mg of nicotine on the filter. Besides, a relatively large quantity of the total nicotine is lost, the output being around 14% at 250°C. At this temperature about 38% remained in the tube after smoking. The missing 42% might have escaped at the intervals during puffs or disintegrated.

Preparation of the Practical Devices Demonstrated on 9th January

For the external heating, Boyard cigarettes were used because they were the thickest that were available to us (diameter 10 mm, length 70 mm). They were treated with 1 ccm of a 20% aqueous solution of KNO_3 and dried. Steel tubes, 4 mm in diameter and 100 mm long, were pushed through the cigarettes and fitted on the protruding end with a cork mouthpiece. These tubes were filled by sucking in a viscous mixture of the extract with alumina powder to which about 1 µl of orange oil has been added.

When smoked, the maximum temperatures within the tube were in the range of 200° to 350°C. The smoke of course had a strong but not unpleasant taste of orange oil, but the throat effect due to nicotine absorption was much less pronounced than in the case were no oil had been added. At any rate it was possible to smoke a complete cigarette and get some satisfaction out of it.

These experiments make it appear very likely that a satisfactory device can be developed. For the moment no further effort will be made on making practical devices, but the work will be concentrated on gathering quantitative design data whereby the electric heating system will be used.

Programme for the Coming Research Period

For the time being we are following strictly the programme outlined in Southampton. The different extracts have been prepared and are now being examined. We would not miss informing you should the course of the experiments necessitate any deviation from or modification of the programme.

Yours sincerely,

H. Schachner