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# A SMOKE GENERATOR FOR USE IN FLUID FLOW VISUALIZATION

J. P. YU, E. M. SPARROW and E. R. G. ECKERT
Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota, U.S.A.

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## INTRODUCTION

Flow visualization can be used to provide decisive insights into the processes which occur in many fluid mechanics and convective heat-transfer problems. In gases, flow visualization is usually accomplished by the injection of smoke. Various ways of producing such smoke have been reported, among which are chemical reactions and burning of combustible materials such as cigars. Some of the methods are of rather limited applicability because they produce smoke which is either corrosive, flammable or toxic. Smoke generators for short-time flow visualization are not difficult to devise, especially for the low rates of smoke utilization appropriate to laminar conditions. On the other hand, long-time visualization of highly turbulent flows requires that a high rate of smoke production be sustained for an extended period of time. This note describes a general purpose smoke generation system that fulfills these requirements while preserving simplicity of construction and operation. In addition, representative flow field photographs of a turbulent, rotating airflow in a cylindrical enclosure will be presented to demonstrate the effectiveness of the smoke generator.

## SMOKE GENERATION SYSTEM

A schematic diagram of the smoke generation system is shown in Fig. 1. The smoke is produced by the burning of wood shavings in a steel pipe. As is seen in the figure, compressed air is ducted to the pipe inlet and, in passing through the pipe, participates in the combustion process. The thus-produced smoke flows through copper tubing to the primary filter, which consists of a steel pipe packed with steel wool. The primary filter is immersed in a water bath to reduce the temperature of the smoke stream. The smoke is then conveyed by plastic tubing to a second filter, which is a glass bottle (to facilitate viewing of the smoke) packed with steel wool. The second filter is provided with two exit ports, one of which leads to the fluid flow test facility while the other of which is a by-pass for venting the smoke.

In the present experiments, the smoke was ducted into a manifold, from which it was distributed to as many as 24 $\frac{3}{16}$ in. dia.) injection holes installed in the walls of the test apparatus. With all 24 holes in use, the smoke generation system provided sufficient smoke for about 25 min of continuous visualization of the flow.

The wood shavings used in the smoke generator were produced with a standard wood-shop planer. White pine was found to be a suitable wood. To load the smoke generator with a charge of shavings, the steel pipe was decoupled from the system. The shavings were introduced from both ends of the pipe and compacted with the aid of a rod. The fully charged pipe was then screwed to pipe reducers at its upstream and downstream ends.

The upstream pipe reducer was fitted with an electrical resistance heating element whose function was to ignite the wood shavings. In order to ensure ignition, shavings were also tightly packed into the upstream pipe reducer. The heating element was coiled nichrome wire, a coil being used to permit stretching and displacement of the element when the shavings were being loaded. Power was supplied to the heating element through a pair of copper connectors

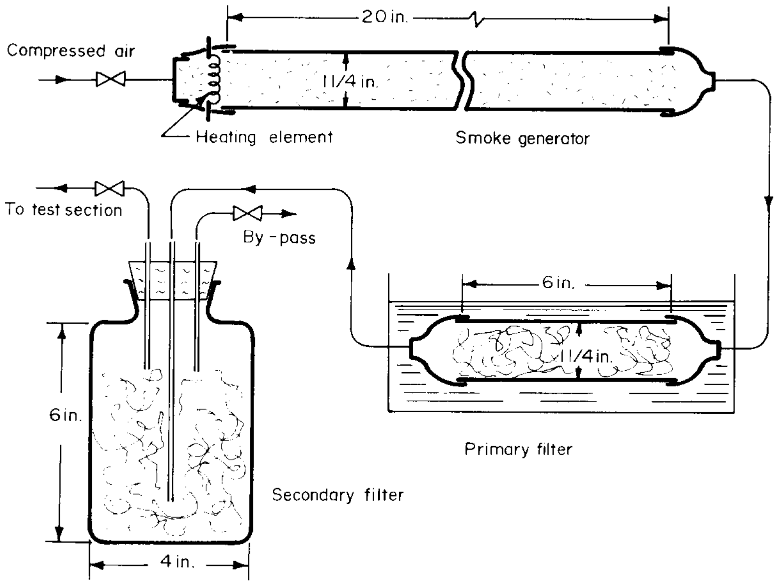


FIG. 1. Schematic diagram of the smoke generation system.

which passed through the wall of the pipe reducer. The nichrome wire was threaded through a small hole drilled in each of the connectors. The heating element was activated only to initiate combustion. Once burning had begun, the power was turned off. The rate of smoke production was controlled by adjustment of a valve situated in the compressed air line upstream of the smoke generator.

## TYPICAL FLOW VISUALIZATION RESULTS

Representative photographs will now be presented to demonstrate the effectiveness of the smoke flow visualization. A schematic diagram of the fluid flow test apparatus is shown at the top of Fig. 2. Air passes through a rotating tube into a cylindrical enclosure. The disk which forms the right-hand face of the enclosure also rotates, with the rotational speeds typically being 3000 rpm. The cylindrical wall and the left-hand face are stationary. The dimensions of the enclosure are approximately 18 × 18 in. (dia. × axial length). Fluid exits from the enclosure through an annular space at the rim of the stationary disk. Smoke is injected into the enclosure through a line of holes axially distributed along the cylindrical wall and a line of holes radially distributed along the stationary disk. The airflow entering the enclosure from the rotating tube is free of smoke.

The photograph in the middle of Fig. 2 shows the traces of smoke injected through the line of holes distributed along the cylindrical wall. The smoke indicates the presence of a strong tangential velocity component and of a lesser axial velocity component directed toward the exit of the enclosure. The lower photograph reveals the presence of a cone-shaped backflow region lying along the axis of the enclosure. The flow entering the enclosure from the rotating tube forms an annular jet (identifiable as the region of lesser brightness) which surrounds the backflow region.

These photographs, which are typical of a much larger number taken by the authors, indicate that the quality (i.e. color and density) and quantity of the smoke are very good for application to flow visualization studies.

## ACKNOWLEDGEMENT

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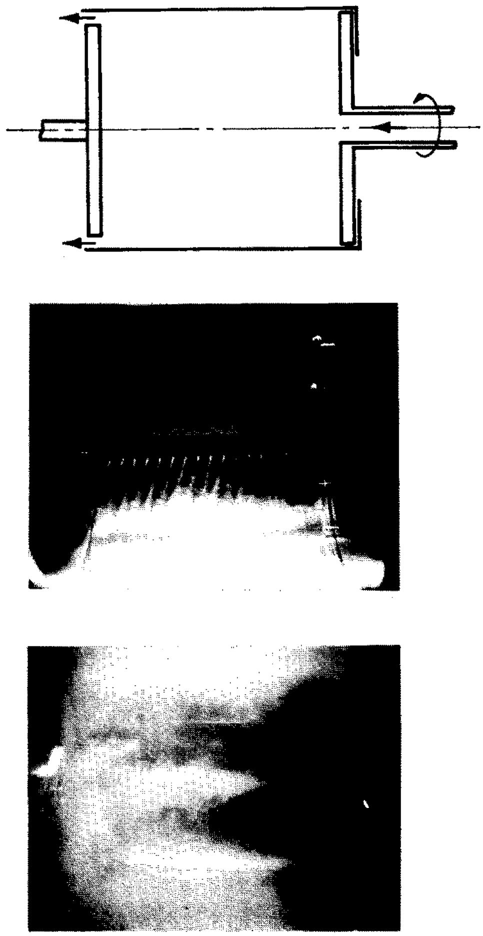

Fig. 2. Fluid flow apparatus and flow visualization photographs.