Engineering Journal of Qatar University, Vol. 1, 1988.

"DESIGN OF SMOKE GENERATOR FOR FLOW VISUALISATION"

By

M.M. Shahin,
Associate Professor,
Faculty of Engineering,
Qatar University, Doha,
Qatar, Arabian Gulf.

ABSTRACT

Described in this paper is an alternative method for smoke generation for flow visualisation in low speed (subsonic) wind tunnel work. This method makes use of the smoke generating characteristics of Ammonia and Sulphur Dioxide mixture. The smoke generated is especially useful for visualisation studies in wind tunnels since the smoke can be produced quickly and uniformly with consistent degrees of repeatability and with minimum attendance of operator. The major disadvantage of this method of smoke generation is that the chemicals used are toxic and care must be taken in handling them.

1. INTRODUCTION

Smoke has many uses in both military and civilian applications. White Phosphorus, Hexa chloroethane — Zinc combustion and Sulphur Trioxide and Chlorosulfonic Acid are today used extensively for that reason. Mists of oil vapour are used in smoke grenades. Pyrotechnic mixtures are also used for generating coloured smokes, however, they are seldom used any more because of fire works safety measures.

For flow visualisation in wind tunnels, burning paper and boiling oil are the common methods of producing smoke. One of the problems with these methods is that considerable time is required to obtain the desired amount of smoke and continuous adjustment is needed to achieve equilibrium conditions.

In the oil smoke method, the oil is heated at the tip of the probe by means of an electric element. This makes the probe rather large. Thus it disturbs the flow and may defeat the object of visualisation. Besides, if it causes the speed of air in the tunnel to be changed, both the oil flow and the temperature of the electric element must be altered. This is due to the fact that when the flow speed is increased, more smoke is required to get the same light scatter and a higher temperature is needed for the electric element to stay hot, because faster moving air cools it more effectively.

The object of the work described in this paper was to devise a new chemical method for smoke generation for flow visualisation and to design a valve system to measure and control the flow of the smoke generating gases and thereby overcome problems of the existing common burning paper and oil methods. This was part of the Author's work as consultant to Messrs Waddle Fan & Engineering Company, Llanelli, U.K., for the assessment of the different designs of their fans and flow meters.

2. CHEMICAL CONSIDERATIONS IN DESIGNING THE SYSTEM

The two gases used to make smoke were Ammonia (NH_3) and sulphur dioxide (SO_2). The Ammonia was used because it it inexpensive and readily available gas. Further, it is easily liquified and has a very sharp smell which helps in detecting any leaks. Sulphur Dioxide was also used as it is a non-flamable gas and reacts easily with other substances including Ammonia to produce smoke.

The chemistry which takes place in the Ammonia-Sulphur Dioxide smoke producing reaction is as follows:

$$2\ SO_2 + O_2 \rightarrow 2\ SO_3$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$
$$NH_3 + H_2O \rightarrow NH_4OH$$
$$2\ NH_4OH + H_2SO_4 \rightarrow (NH_4)_2SO_4 + 2\ H_2O$$

As the two gases are known to be toxic and corrosive, the following points were taken into consideration:

1. Care was taken to avoid skin contact and/or inhalation of the gases.

2. Special care was also taken to avoid the Sulphur Dioxide coming in contact with water before it reacted with the Ammonia. Therefore, rotameters, pipes, and

all fittings were carefully dried before assembly to prevent any formation of Sulphuric Acid (H_2SO_4) in the tubes.

3. Some steam was intentionally injected in the stream of air to help the reaction between the two gases as they emerge from the hypodermics. The steam was also used to ensure preventing having any excess amount of toxic Sulphur Dioxide in the smoke by combining with it and forming a less harmful product (Sulphuric Acid) as indicated in the previous equations. This acid was then carried away by the stream of air.

4. Brass compression fittings in conjunction with natural nylon pipes and stainless steel hypodermic tubing were also used throughout to resist any corrosive action by the gases used.

5. All threaded joints were initially sealed before assembly to prevent any possible leaks. This was done using a sealing tape, wound round the threads before they were first engaged.

6. Particular attention was also given to avoid producing dangerous by-products such as Nitrogen Oxide which explodes when found in the ratio of three to two with Ammonia + Nitrous Oxide. Therefore an excess of Ammonia was used. This, in addition to avoiding having the Nitrogen oxide in a ratio enough to cause an explosion, also allowed for maximum reaction to take place which prevented the formation of such by-products from the beginning.

3. DESCRIPTION OF EQUIPMENT

An axial flow compressor, driven by a variable speed motor, was used to provide the air flow for the wind tunnel and honey combs were used to straighten it out. The effect of changing the motor speed on the air flow (wind speed) was established. This helped in obtaining an easy and quick method for varying, accurately, the latter.

To control the flow of each gas, two valves were used (Figure 1). Valve (A) was used not only for controlling the flow of Sulphur Dioxide but also for controlling, in an indirect way, the flow of Ammonia through the effect of its output pressure on valve (B). The latter, valve B, was used mainly for controlling the ratio between the pressures of the two gases. This was done by a 'screw driver" type adjustment. Once this adjustment was made, the ratio was infrequently changed.

All piping and connections, as mentioned before, were designed taking into account the corrosive nature of the gases. Various nozzle designs were considered so as to obtain the most efficient mixing of gases and obtain the required range of smoke grades. This was achieved using different sizes and configurations of hypodermic pipes. These grades, which have numbers from 1 to 4, were used as reference to density of smoke (i.e. the higher the grade number, the higher and thicker was the density of the smoke.

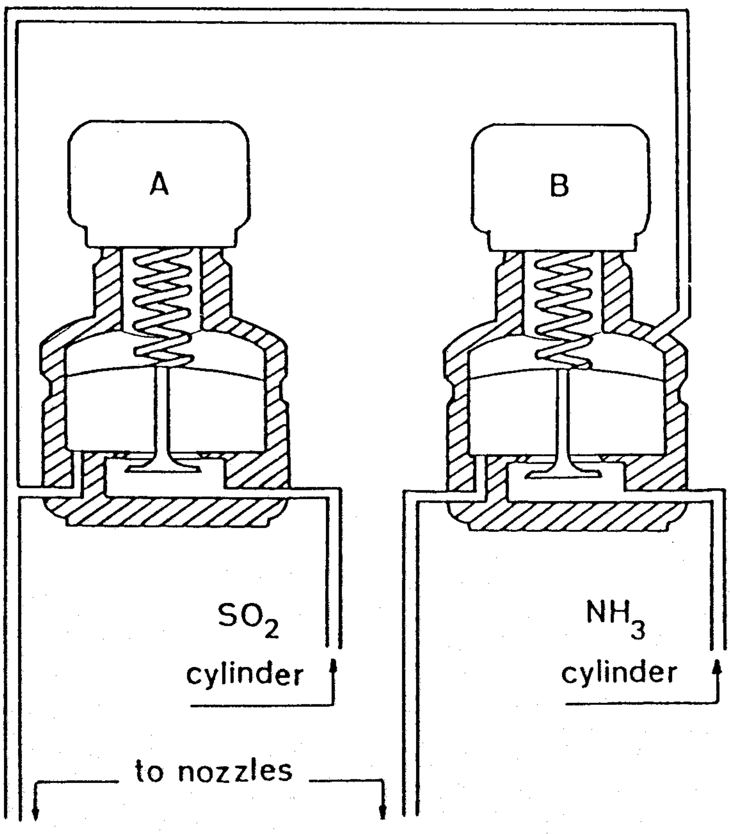


Figure (1): Control System of Gas Flow Rates.

Valve 'A': Pressure Control
Valve 'B': Ratio Control

4. SETTING AND TESTING THE SYSTEM

The relation between the motor and wind speeds was first established. The motor speed was measured by a tachometer and the wind speed was measured by the difference between the stagnation and static pressures using a pitotstatic tube and manometer.

Values of flow rates of constituent gases for different smoke grades at different wind speeds (Figure 2) were then decided by comparing the smoke produced by this method with another produced by a conventional oil burning smoke generator. Two sizes of hypodermic nozzles were also chosen (0.5 and 0.75 mm O/D) to provide the required flow rates.

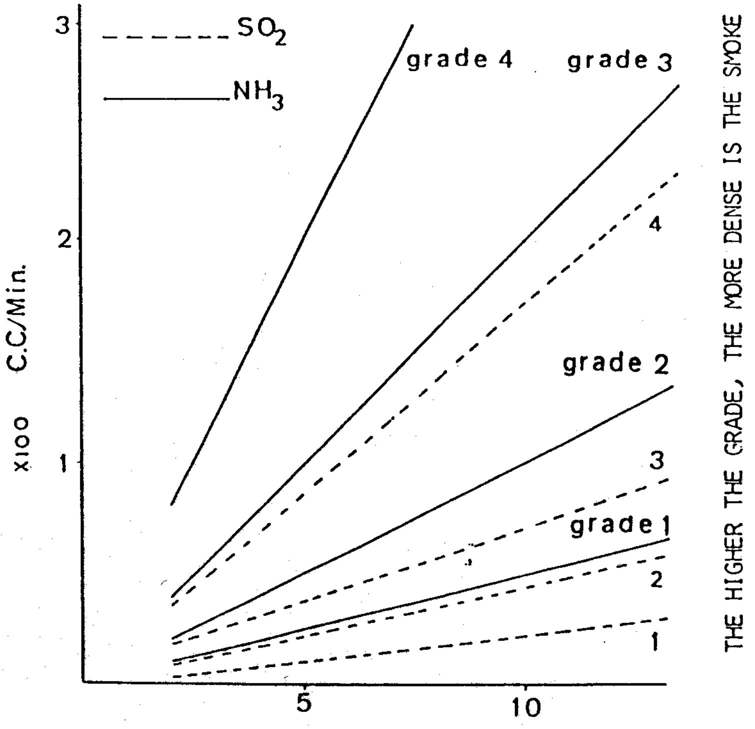


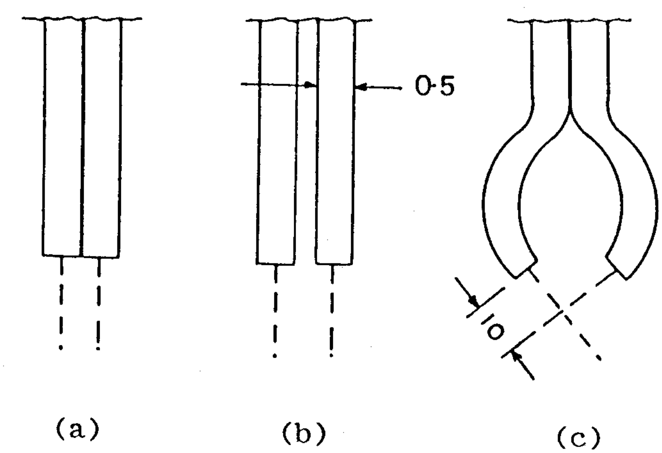
Figure 2: Flow Rates of Gases for Different Grades of Smoke.

These hypodermics were soldered together, using an appropriate flux (Figure 3-a). At this point, a problem was identified. The two emerging gases mixed on contact and formed deposits on the Sulphur Dioxide hypodermic especially at low pressure. This caused partial, and sometimes complete, blocking after minutes of operation. To overcome this, nozzles were separated by about 1 mm (Figure 3-b). However, this caused inefficient mixing of gases. Therefore, the two hypodermics were made convergent (Figure 3-c) so that their projected centre lines met at about 10 mm from their ends. This ensured good mixing and avoided building up of deposits.

Suitable rotameters for monitoring flow rates were selected ensuring that their floats and tubes would not be affected by the corrosive nature of gases.

DIMENSIONS IN MM

DRAWING NOT TO SCALE FOR ILLUSTRATION



a) First design causing deposits
b) Separated tubes: no deposits but poor mixing
c) Converging tubes: no deposits & good mixing

Figure 3: Designs of Gas Flow Nozzles.

A set of graphs were then established (Figure 4) to provide the necessary information needed by the operator to set-up the flow rates of the two gases and select the nozzle sizes of the two hypodermics, knowing the grade of the smoke required and the speed of the wind available.

The system was then tested following the steps indicated below:

1. The grade of the smoke required was decided.
2. The speed of the wind was determined.
3. The rates of flow of the two gases and the sizes of nozzles of the two hypodermics were chosen from corresponding information in Figures 2 and 4 respectively.

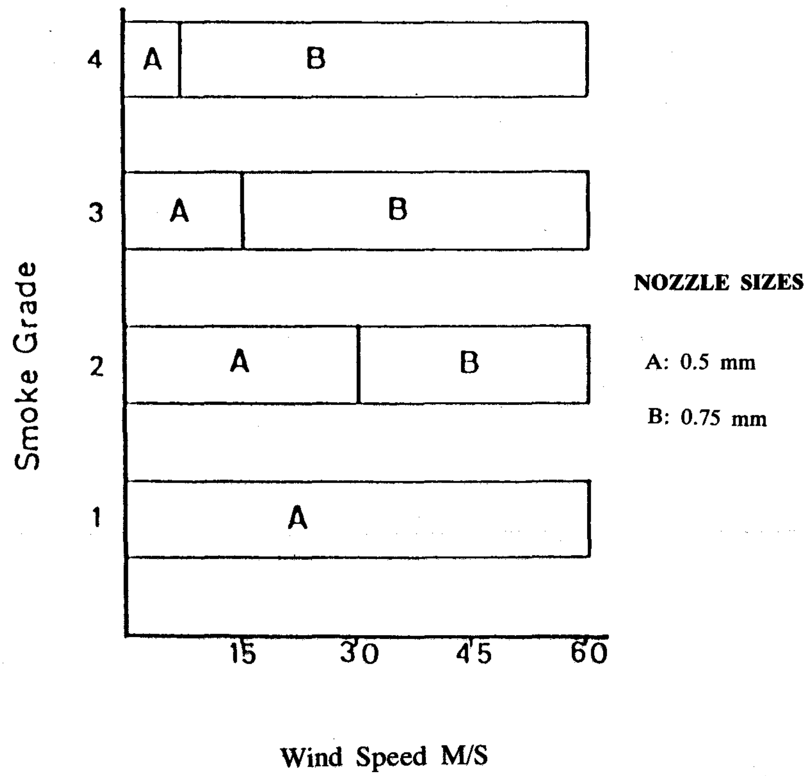


Figure 4: Selection of Nozzle Sizes.

5. RESULTS AND OBSERVATIONS

The following were noticed during the work:

1. The correct mix of gases was judged quite accurately by the colour of the smoke produced. The smoke turned blue when there was an excess of Sulphur Dioxide and brown when an excess of Ammonia existed. As an excess of Ammonia was desirable, as described in the section on chemical considerations, a slightly brown smoke was selected for normal operations.

2. It was also observed that both gases and their products of reaction are soluable in water. This fact was relied upon to stop any build up of Ammonium Sulphate powder $(NH_4)_2SO_4$ on the object around which the flow was to be visualised. Injecting some steam in the stream of air (with amount slightly higher than the sum of the rates of the two gases used) proved to be effective and helped both the reaction between the two gases (Ammonia and Sulphur Dioxide) and any reaction involving harmful by-products to eliminate the danger.

3. This chemical method for smoke generation was found to be, almost instantaneously stable. Comparing this with the conventional oil smoke generation, the latter was found to take about ten minutes to find its equilibrium condition.

6. CONCLUSIONS

As the most common method for producing smoke is by boiling oil, a comparison was made between this method and the present chemical one. The following advantages were found for the chemical method over the oil method:

1. The required smoke can be quickly obtained once the desired smoke grade and wind speed are decided upon.

2. The total size of the 'smoke probe' in the chemical method, using two small hypodermics, is far smaller than an oil probe with its incorporated electrical element. Thus, less obstruction of air flow was achieved.

3. The chemical smoke can be adjusted from one grade to another very quickly, as where an oil heater element takes considerable time to reach an equilibrium condition.

4. The smoke can also be switched off and restarted again with ease so that it is practical to stop the smoke while adjusting the wind speed or model position, thus keeping the atmosphere in the laboratory relatively clean.

5. The oil smoke generator tends to be rather messy as oil can be spilt and collect dust. Thus mess is inevitably transferred to the model, the wind tunnel and any other equipment that is nearby.

Against the above mentioned advantages, care must be taken due to the toxic and corrosive nature of the gases prior to their reaction with each other to produce the smoke.

REFERENCES

1. **Bradshaw** and **Parkhurst, R.C.:** *"The Design of Low Speed Wind Tunnel"*, NPL AERO REP. 1039, 1962.

2. **Parkhurst R.E.** and **Holder, D.W.:** *"Wind Tunnel Technique"*, Sir Isaac Pitman & Sons Ltd., 1952.

3. **Austin, G.T.:** *"Shreve's Chemical Process Industries"*, McGraw-Hill, 1984.

4. **Iowenheim, F.A.** and **Moran, M.K.:** *"Industrial Chemicals"*, John Wiley & Sons, 1975.