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CRI TECHNOLOGY DIGEST

CEMENT RESEARCH INSTITUTE OF INDIA

IMPROVED DESIGN OF CYCLONE SEPARATORS

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INTRODUCTION

Cyclones are conventional dust collectors used in the cement industry for preliminary dedusting of exit gases from crusher, raw mill, coal mill, cement mill, kiln etc. In general, cyclones are utilized for the separation of coarser particles and have the advantage of simplicity, moderately high efficiency and medium pressure drop.

Cyclones have been the subject of extensive research in the past few decades. Considerable work has been reported on the mechanism of dust separation in cyclones and also on the evaluation of cyclone parameters through model development and subsequent testing of the same in the laboratory. It is apparent from these works that the cyclone performance can be considerably improved through rational design approach and suitable control of the operational parameters.

In the light of the above background, CRI has undertaken a R&D project for a thorough investigation into all aspects related to cyclone design and has been able to develop methods to ensure improved performance of cyclones. The findings can be applied to the design of new cyclones and modification/rationalisation of existing cyclones so as to achieve improved operational characteristics.

PRINCIPLE OF OPERATION OF CYCLONE SEPARATORS

Particle collection in a cyclone separator occurs essentially by the action of centrifugal forces. This is made possible by introducing the gas tangentially into the cyclone. The flow pattern of the gas and the distribution of tangential velocities play a vital role in influencing the performance of cyclones.

When the gas (or suspension) enters the body of the cyclone tangentially, two vortices, one outward vortex moving downwards and another inward vortex moving upwards (Fig 1), are generated. The outer vortex moves radially inward into the central core of low pressure region which extends below the gas exit duct. Upon reaching the central core, the cleaned gas moves up in the inner vortex and finally, out of the cyclone through the gas exit duct.

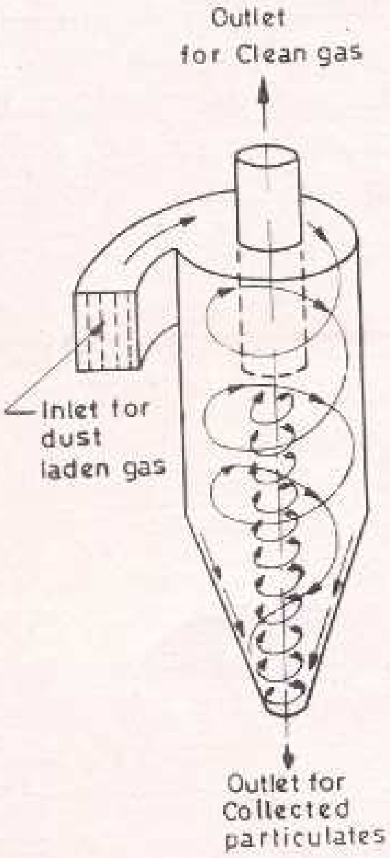

Fig 1 Inner and outer vortices in tangential entry cyclone

The characteristics of outer vortex are, by and large, determined by the inlet dimensions of cyclone and that of the inner vortex by the diameter of the gas exit pipe (also called vortex finder). The performance of the cyclone is determined by the relative characteristics of outer and inner vortices which are, in turn, dictated by the inlet and vortex finder dimensions. Careful consideration of these dimensions is therefore required for improved performance of cyclones.

DESIGN PARAMETERS OF CYCLONE

A cyclone is specified by its diameter and seven dimensions. These include inlet height, inlet width, vortex finder diameter, vortex finder depth, cylinder height, overall height and dust outlet diameter (Fig 2). Corresponding to each of these dimensions, seven dimension ratios can be defined by dividing the particular dimension with the cyclone diameter. Standard values of these dimension ratios are well documented and are based on operational experiences. These values can be used for the design and analysis of cyclones either in their present states or in forms (as dealt in the present R&D work) that have been obtained after modification through optimisation techniques.

OPERATIONAL PARAMETERS OF CYCLONE

The operational parameters which are characteristic of the process

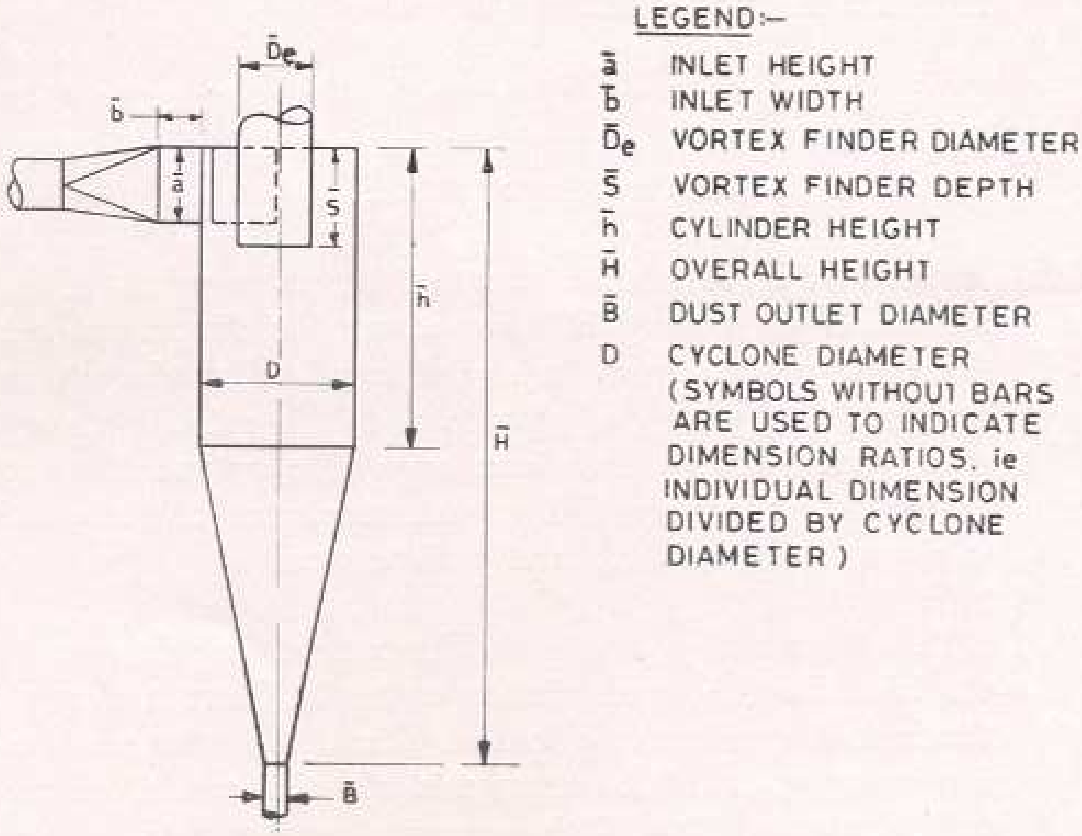

Fig 2 Design configuration for tangential entry cyclones

and influence cyclone performance are the gas flow rate, temperature, pressure, concentration and particle size distribution of the dust in the inlet gas and the density of particles. Changes in these parameters are likely to alter the cyclone performance. It is imperative, therefore, to monitor these parameters so that in the event of any permanent change foreseen, the design parameters can be altered to ensure good performance of cyclone. This aspect has been considered in details in the present R&D work.

PERFORMANCE PARAMETERS OF CYCLONE

The performance of cyclone is measured in terms of the collection efficiency and pressure drop. The fractional efficiency is determined by dividing the weight of particles of a stated size collected in the cyclone with the total weight of particles of that size going into the cyclone. The relationship between the fractional efficiency and particle size is described in the fractional efficiency curve (Fig 3). As can be seen, the efficiency steadily increases with increasing particle size and thereafter, asymptotically approaches unity for very large particles.

The overall efficiency of cyclones can be known from a knowledge of the fractional efficiency and particle size distribution of the inlet dust. Dust concentrations can be measured and cumulative undersize plot (in weight percent) constructed. From the curve, the weight fractions of particles of different sizes can be obtained. The algebraic sum of the product of the fractional efficiency and weight fraction of each of particle sizes will give the overall efficiency. It can be determined by measuring the dust concentration at the exit and inlet ends of the cyclone. Thus :

$$\text{Percent efficiency} = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100$$

where C is the dust concentration in g/m^3

The pressure drop in a cyclone is determined between a point adjacent to the inlet duct and a point at the outlet duct immediately after the cyclone. The main factors contributing to pressure drop are the loss as kinetic energy of rotation and that due to wall friction in the cyclone chamber. The pressure drop is generally expressed as the product of the number of velocity heads and the velocity head (mmWG). Reasonable pressure drops in cyclone design fall in the range 75—125 mmWG.

Models for Cyclone Performance

The fractional efficiency and pressure drop can be explained with the help of models proposed by various researchers. The Leith and Licth model for fractional efficiency and Shepherd and Lapple model for pressure drop are reported to be reasonably good. The optimum velocity and overall efficiency can be found with the help of these models and similar other R&D works.

Design and Analysis of Cyclone Performance

Based on the above approach, procedures have been evolved for

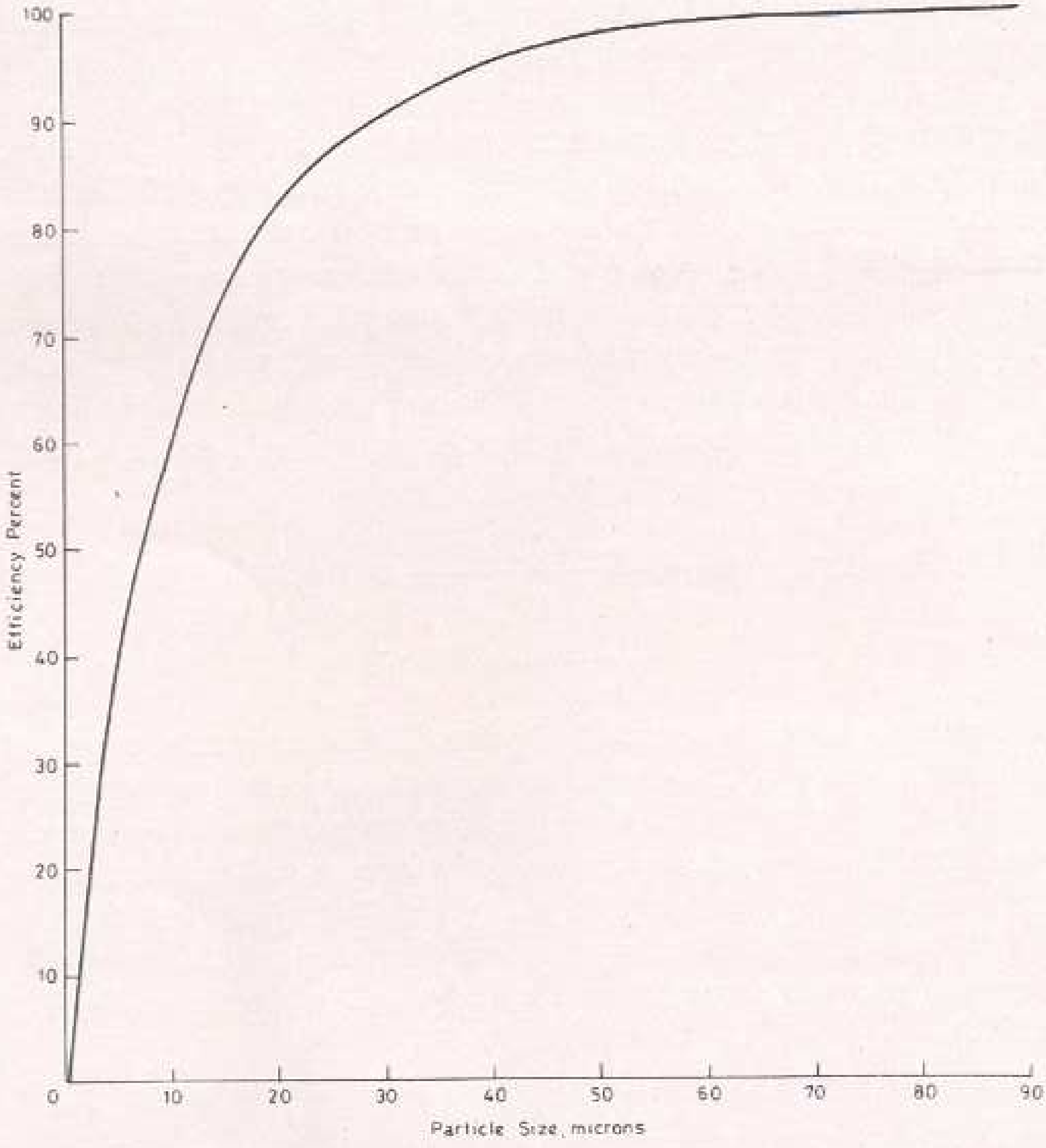

Fig 3 Typical fractional efficiency curve of cyclone

the following cases :

i) Prediction of efficiency and pressure drop of operating cyclones.

ii) Determination of possible changes in performance due to the changes in the operating or design parameters. Appropriate measures to be taken to ensure the existing or enhanced performance in such cases.

iii) Design of cyclone using specified dimension ratios. Either the standard values or any set of such practicable dimension ratios can be used in this procedure.

iv) Determination of optimal vortex finder dimensions. This is applicable particularly in cases where the dimensions other than that of the vortex finder are found to be adequate and favourable to good performance and it is sufficient to optimise vortex finder dimensions only. The optimisation technique further ensures design with maximum efficiency with minimum pressure drop and surface area.

v) Determination of optimal inlet dimensions. In this case also, the inlet dimensions are chosen optimally. Since a change in the inlet dimensions may lead to alteration in the gas handling capacity, in some cases, this may be considered as a fresh design problem. This case also ensures maximum efficiency with minimum pressure drop and surface area.

vi) Maximisation of efficiency : In this case, only the efficiency is maximised and several possible designs for pressure drop and surface area are to be examined and selection made accordingly.

The above optimisation problems necessitate an iterative solution. However, the iterations are found to converge faster. The procedure is amenable for programming in a desk calculator. Owing to its simplicity, this can also be solved using a pocket calculator.

MODIFICATION IN THE CONFIGURATION OF CYCLONES

In order to improve the cyclone performance, certain modifications in the configuration were also made. Such studies were particularly made with regard to vortex finder. Indeed, this was found to enhance the cyclone performance. The modification in the vortex finder shape is easy to adopt. Although this modification results in an increase in the pressure drop (together with the increase in efficiency), suitable measures can be taken so as not to exceed the permissible range of pressure drop. Improvement in the performance has been confirmed by experimentation in a pilot size cyclone as well. Although the other techniques experimented, have significant potential for application, further study as regards the optimisation of parameters involved therein would prove useful.

APPLICABILITY OF THE FINDINGS FOR IMPROVED CYCLONE PERFORMANCE

The methods evolved for the design of cyclones through optimisation technique or for improving the performance of the existing cyclones are simple to apply. These are also amenable for computation in a desk or pocket calculator. For the existing cyclones as well as the design of new cyclones, the modification in the vortex finder configuration can be applied owing to its effectiveness. Other methods of improvement of performance can be examined in more details. These findings, resulting from CRI R&D work, can be translated for implementation in the cement industry and CRI would be in a position to offer its services to cement plants as well as machinery manufacturers.

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