ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1990

Seria: INŻYNIERIA ŚRODOWISKA z. 31 Nr kol. 968

S. MIERZWIŃSKI, W. NAWROCKI
J. PIOTROWSKI, Z. TRZECIAKIEWICZ

Institute of Heating, Ventilation and Air Protection
Silesian Technical University

AERODYNAMICAL PROBLEMS OF POLLUTION SOURCES ENCLOSURES IN INDUSTRIAL HALLS

Summary. The problem of pollutants intake construction is essential for atmosphere protection in industrial halls. The intakes actually dosigned involve considerable energy consumption or they do not always work efficiently. The choice of construction parameters of the intake, of the amount of removed gases and of their parameters requires an experiment. The paper presents the possibility to apply physical modelling to analyse various design conceptions and to choose the proper range of exploitation parameters. The accuracy obtained in this approach is given for metallurgical furnaces equipped with exhaust hoods. The weights of such the intake efficiency and of its aerodynamical characteristic are also discussed. In result of the tests treble reduction of pollutants concentration was obtained at work places at significant reduction of costs.

Introduction

Technological sources of dust or gas pollution contribute to indoor climate deterioration in many industrial rooms. This inconvenience can be reduced by means of local exhausts equipped with suction nozzles, hoods or air-tight sealing enclosures. When designing such the pollutants intake it is difficult to choose the advisable aerodynamical shape and to determine sufficient air amount that are of essential importance for air protection in industrial halls.

The advisable shape and exploitation parameters values cannot be calculated precisely in the common design practice. This results from the fact that their determination requires an experimental analysis of various shapes on account of air velocity distribution obtained within the intake area when considering specific character of aerodynamical effects and exploitation conditions of technological equipment being the sources of seized pollutants.

Such the experimental analysis can be, on certain conditions, performed by means of physical modelling. On this way it is possible to determine the set of the intake parameters (searched according to an assumed criterion) e.g. to choose the shape of the intake that enables to obtain the required efficiency of pollutants removal at suitably low energy consumption and air discharge.

Such the experimental research and its results are presented on the example of hood shape intakes of dust polluted gases discharged from metallurgical furnaces.

Assumptions for Model Tests

In model tests the choice of similarity conditions depends on physical-chemical properties of a modelled phenomenon. It is therefore necessary to know thoroughly the industrial object and to characterize phenomena that are to be modelled [1, 2].

In the case under consideration this refers mainly to those periods of a technological process that are the least advisable from the point of view of exhaust and gas cleaning installations. For those periods it is necessary to determine mass and energy balances as well as other data necessary to carry out model test. The periods discussed are those causing significant strenuousness and air pollution in halls, up to even 100 mg/m^3.

Two gas intakes of a hood shape, one of a melting furnace and the other of an electric arc furnace, were chosen as test objects. The melting furnace was for copper refining, it was fuel gas-fired and its capacity was about 40 Mg whereas the arc furnace was for steel refining and its nominal capacity was 6 Mg.

The heat balances of both the furnaces were calculated in relation to the technological cycle on the basis of the material balance of components used for melt and leaving the furnaces.

Time changes of particular items of the material balance were determined for modelling purposes on the basis of the changes in the substantial balance of a real furnace in the considered melt phases.

The mean values of parameters that were assumed to model hoods over the charging doors of the furnances were determined on the basis of measurements carried out in industrial objects.

Principles of Experiment

In the case of an intake of a hood shape, the modelled processes can be reduced to mechanically forced and convective motion of pure gas and aerosol. In result, geometrical, mechanical and thermal similarities must be fulfilled whereas the defining similarity criteria are the numbers:

Re, Gr, Ar, Pr. In the problem presently discussed only the mechanical similarity was taken into account.

In natural conditions it is not possible to keep the equality of all these criteria in a natural scale object and in a small-scale model at the same time therefore a method of simplified modelling was applied [2].

To this purpose the equality of Ar numbers was ensured and the forced and convective gas motion was maintained within the self-similarity range in reference to the distribution of the mean velocity of turbulent flow. This occured when $Re > Re_g$ and $Gr \cdot Pr > 2 \cdot 10^7$. The relation $Eu = f(Re)$ was determined, the value of which is constant in the case of turbulent flow and it may be used to control the self-similarity range.

In the case discussed it was assumed that the linear scale $S_1 = 0{,}1$, the temperature difference scale $S_{\Delta t} = 0{,}6$ and the acceleration of gravity scale $S_g = 1$. The density scale was $S_\rho = 1$ since it was also assumed that air would be used in a simplified model.

From the point of view of aerodynamics, so-called initial stages of flow, in which stabilization begins, contribute significantly to hoods over furnaces. Thus, in this case the full self-similarity of the flow, necessary for the principles of simplified physical modelling to hold true, cannot be expected. Taking into account this fact, the aerodynamical phenomena occurring within the intake of a hood shape, were characterized by means of parameters referring to flow in the exhaust connector pipe.

Thus, the intake was tested as a whole to which the elements of simplified similarity contributed only to some extent. Their effect on the tests results was revealed by comparing the results of the measurements in industrial objects and in the model. The measure of mechanical similarity unfulfilment may be in this case the discrepency between Euler numbers in the industrial enclosure and in its model.

It was found that the flow of air leaving the furnaces and modelling the flue gases in the scale S_V was a good representation of the industrial conditions (the equality of Ar numbers) of the hood shape intake performance. This was also confirmed by observation in industrial objects.

The hoods efficiency was determined on the basis of qualitative tests by means of observation how a smoky air jet leaving the furnace was captured by the hood and quantitatively by balancing the amount of CO_2 dosed into the air.

Model Tests Results

The model tests on gas intake improvement referred mainly to:

- Determination of aerodynamical characteristic of a hood variant actually tested.
- Improvement of the exhaust hood shape on the basis of measurements of static pressure distribution inside the hood.
- The choice of the necessary amount of exhausted gases on the basis of tests of the gas intake efficiency.

In order to obtain the assumed efficiency of the intake (depending on its shape), different amounts of exhausted gas and adequate pressure drops are required.

Gas intake construction may be considered satisfactory when the intake shape ensures the required efficiency at sufficiently low amount of gases exhausted. Thus, for the purpose of efficiency testing it is necessary to know the gas intake aerodynamical characteristic.

The aerodynamical characteristic of a gas intake of a hood shape is described by the relation between the static negative pressure in the exhaust connector pipe and the amount of air passing through the air velocity in the connector pipe:

$$\Delta P = r_1 \cdot V^2 \quad \text{or} \quad \Delta P = r_2 \cdot w^2$$

where r - hood resistivity, Pa . $s^2/(cm^3)^2$.

This relation characterizes the whole hood as local resistance. When such the characteristic is completed with static pressure distribution measured inside the hood, it is possible to choose various design solutions and to improve again their shapes.

Hood for the Copper Melt Furnace

It was found that owing to present restrictions in placing the hood on the furnace it is necessary to maintain relevantly high mean velocity at the inlet, equal 5,5 m/s, in order to obtain the required hood efficiency independently of the hood construction. The amount of exhausted gases necessary in this case is $V = 9{,}5\ m^3/s$. Fig. 1 shows an exemplary model of one of the tested hoods performance.

The research was aimed at such the modification of the hood shape that it would be possible to obtain an aerodynamical characteristic showing the least pressure loss for given conditions of work and the way of placing the hood. The comparison of the characteristics of differently shaped hoods A, B, D is shown in fig. 2a. It shows also the reduction in pressure loss for the hood D in comparison with the hood B installed on the industrial furnace that for the amount of exhaust gases 9,5 m^3/s equals 1055 - 655 = 400 Pa.

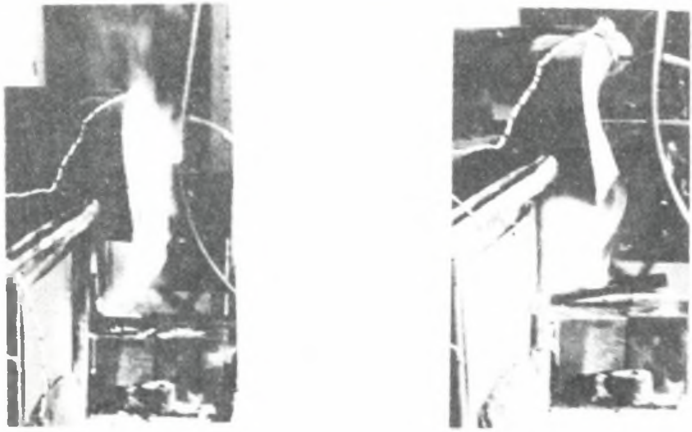

Fig. 1. Work of the hood B modelled at various amounts of exhaust gas for the stream $3 < Ar < 5$

a) 5,8 m^3/s, b) 9,8 m^3/s

Rys. 1. Działanie okapu B, modelowane przy różnych ilościach odciąganego gazu dla strugi $3 < Ar < 5$

a) 5,8 m^3/s, b) 9,8 m^3/s

Therefore it appears that after the hood D is constructed over the furnace, it will be possible to obtain about 40% reduction of the pressure loss resulting from the flow; thus it will be possible to reduce energy input for the exhaust performence also in about 40% in relation to the exhaust actually working.

Placing the hood over the charging door of the furnace for copper scrap melt reduced more than three times the concentration of lead dioxide condensation dust at the work stand near the furnace.

Hood for the Electric Furnace for Steel Melting

In the hood shape intake of waste gases in an arc furnace two parts, functionally different, can be separated, namely:

- The part comprising the furance roof with electrode openings, being an air-tight sealing enolosure
- The part protruding over the charging door being a classical hood.

Both parts of the intake are connected to the common exhaust connector pipe and there is a gate placed where streams join together in order to obtain proper shares of exhaust air.

In industrial objects various design solutions are applied for gas intakes and for exhausts from electric arc furnaces; therefore they were

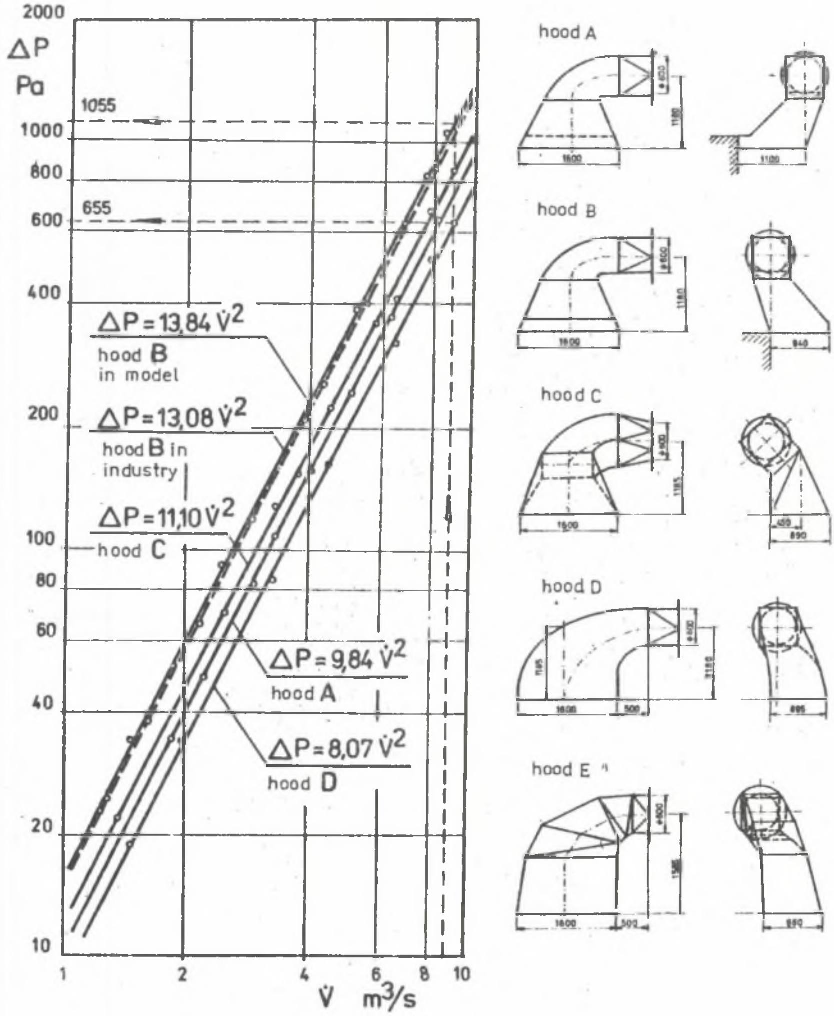

Fig. 2. Aerodynamical characteristics of hoods for
a) the copper melt furnace
Rys. 2. Aerodynamiczne charakterystyki okapów dla
a) pieca do wytopu miedzi

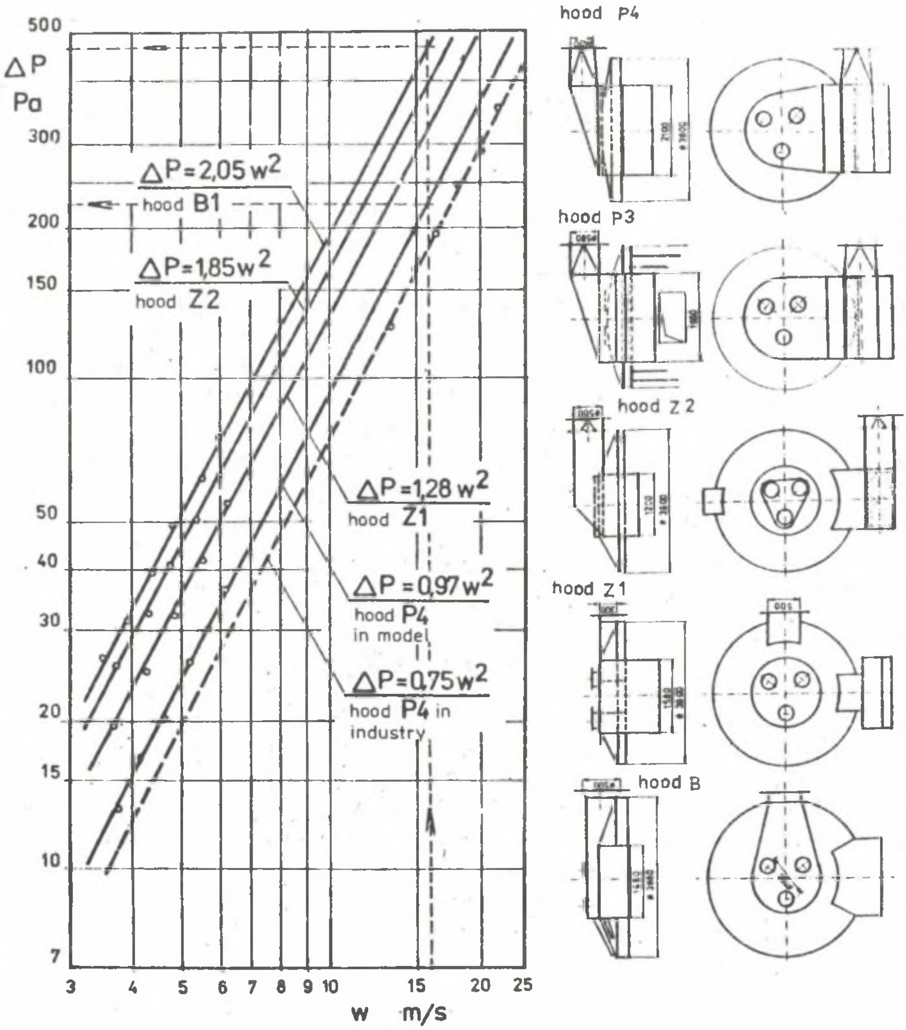

Fig. 2. Aerodynamical characteristics of hoods for b) the electric arc furnace

Rys. 2. Aerodynamiczne charakterystyki okapów dla b) elektrycznego pieca łukowego comprised in the research (hoods B1, Z1, Z2) being the starting points for further improvements (hood P4).

Aerodynamical characteristics for these hoods are shown in fig. 2b. The least favourable pressure distribution is observed in the gas intake B1. This intake works efficiently only at the exhaust rate $V = 4,86\ m^3/s$ that corresponds to the velocity 17 m/s in the exhaust connetor pipe.

From this point of view the shapes of the intakes Z1 and Z2 also are not advisable. Therefore, when working out a new improved shape the efforts were made in order to remove the apparent drawbacks such as wrong location of the connector pipe, wrong construction of the gate, too small cross-sections of connecting ducts etc.

After several trials the hood P4 was chosen as the best on the account of aerodynamics. It was found that with respect to other cases tested this gas intake efficiency is satisfactory already when gas exhaust rate is $V = 2,64\ m^3/s$ that corresponds to the velocity in the connector pipe 16 m/s.

When comparing energy inputs only for the latter parameters (see fig. 2b) it is apparent that they are reduced more than 50% in comparison to the intake B1. Taking into account the fact that when applying the improved hood P4 also the amount of exhausted air is about 46% less, the proper indoor climate conditions are obtained at significantly lower cost.

Errors in Model Tests of Hood Aerodynamical Characteristic

The error of hood aerodynamical characteristic determination in the model results from the fact that mechanical similarity is not fulfilled for certain elements e.g. slots. In order to define this error, aerodynamical characteristics of the modelled and industrial exhausts are shown in fig. 3 by means of the criterion $Eu = f(Re)$.

The revealed discrepancy of Eu numbers for the industrial and model hoods calculated, as an istance, for the hood P4 is:

$$p = \frac{Eu' - Eu''}{Eu} = \frac{0,80 - 0,95}{0,80} = -0,19\ (-19\%)$$

Taking into account measurement errors whose average values were $\pm$ 4,5% in the model and $\pm$ 7,5% for industrial measurements it may be assumed that owing to not fulfilled simplified modelling conditions the discrepancy in aerodynamical characteristic determination on the basis of model tests may range from 8% up to maximum 30%. These results may be considered satisfactory since there is still the effect of factors that

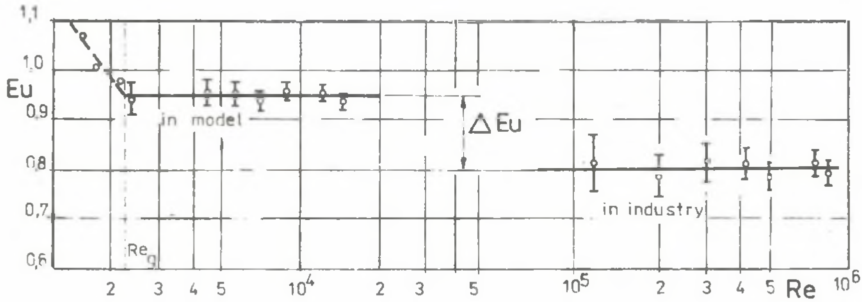

Fig. 3. Dimensionless characteristic of the hood P4 obtained on the way of modelling and from the industrial tests

Rys. 3. Bezwymiarowa charakterystyka okapu P4 otrzymana na drodze modelowania i z badań przemysłowych

cannot practically be influenced by a designer, e.g. same leaks resulting from defermation that is the effect of high temperature or the changes of the hood shape revealed in its exploitation, whereas when designing such the hoods erroneousnesss is from 1 to 4.

Conclusions

1. Implementation of the research proved its practical usability and the advantages of physical modelling application in studies on air-tight sealing efficiency improvement. On the basis of model tests it was possible to determine the hood shape and its aerodynamical characteristic accurately enough for design needs.

2. The tests carried out at work-places near industrial furnaces proved that when installing hoods, whose parameters were determined by means of model tests, it was possible to reduce more than three times pollutants concentration in air at the work places in the hall.

3. It was proved that it was possible to get 40-50% energy saving in relation to the analysed industrial constructions for hoods over the tested metallurgical furnaces. The method may be also applied to test and analyse other cases of room ventilation.

REFERENCES

[1] Johnstone R.E. and Thring N.W.: Experimental installation, models and methods of scale enlargement. PWN, Warszawa 1960.

[2] Mierzwiński S.: et al. Application of physical modelling in the study on reducing the strenuousness of dust sources. New Technology in Sanitary Engineering, No 6, Heating and Ventilation, Arkady, Warszawa 1976.

[3] Müller L.: Principles of similarity theory. Engineering aids. Vol. 1, WNT, Warszawa 1968.

Recenzent: Doc. dr inż. Jerzy Makowiecki

Wpłynęło do Redakcji 4.03.1988 r.

AERODYNAMICZNE PROBLEMY OBUDÓW ŹRÓDEŁ ZANIECZYSZCZEŃ W HALACH PRZEMYSŁOWYCH

S t r e s z c z e n i e

Rozwiązanie ujęcia zanieczyszczeń ma istotne znaczenie dla ochrony powietrza w halach przemysłowych. Projektowane ujęcia mają duże zużycie energii lecz nie zawsze działają skutecznie.

Dobór parametrów konstrukcyjnych ujęcia, ilości i parametrów usuwanych gazów wymaga przeprowadzenie eksperymentu. W referacie przedstawiono możliwości zastosowania fizykalnego modelowania do analizowania różnych koncepcji rozwiązań i doboru właściwego zakresu parametrów eksploatacyjnych oraz uzyskiwaną dokładność w tym zakresie na przykładzie pieców hutniczych zaopatrzonych w okapy odciągowe. Omówiono rolę skuteczności działania i charakterystyki aerodynamicznej takich ujęć.

W wyniku badań uzyskano 3 krotne zmniejszenie stężeń zanieczyszczeń na stanowiskach pracy przy znacznym obniżeniu kosztów ruchowych.

АЭРОДИНАМИЧЕСКИЕ ПРОБЛЕМЫ КОРПУСОВ ИСТОЧНИКОВ ЗАГРЯЗНЕНИЙ В ПРОМЫШЛЕННЫХ ЦЕХАХ

Р е з ю м е

Решение каптажа загрязнений имеет существенное значение для охраны воздуха в промышленных цехах. Проектированные каптажи характеризуются большим расходом энергии и тем, что не всегда работают эффективно. Подбор конструкционных параметров каптажа, а также параметров и количества удаляемых газов требует проведения эксперимента.

В настоящей работе представлены возможности применения физического моделирования для проведения анализа концепций разных решений и подбора нужного диапазона эксплуатационных параметров, и получаемая в этом диапазоне точность на примере металлургических печей с вытяжными зонтами. Обсуждены тоже роли эффективности действия и аэродинамической характеристики таких каптажей. В результате исследований концентрация загрязнений на рабочих местах уменьшилась в 3 раза при одновременном значительном снижении расходов.