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INVESTIGATIONS OF OIL MIST SEPARATION IN INJECTION CONTACTOR

PART I. CURRENT REPORTS. CONCEPTION OF A NEW SEPARATION METHOD AND EXPERIMENT DESIGN

The so far known methods of oil mist separation from the air polluted during the work of machine tools have been described. A new idea of separation process in an injection contactor with a spontaneously circulating liquid has been presented. A laboratory installation set to study this process as well as the methods for the measurements of mist concentrations have been described. A new design of oil mist generator and its operation parameters have been characterized.

1. INTRODUCTION

In most metal machining processes, done by cutting (turning, milling, boring) and grinding, a liquid cooling of the piece being machined is necessary to prolong the life of cutting tools, being indispensable in high-speed and automatic machines. Two basic oil coolants are applied:

pure oils (e.g. machine oil or spindle oil) used mainly in automatic machine tools,

water–oil emulsions.

Although the liquid coolants eliminate dusting, they become another source of air pollution with mist and vapours of oil as well as with gaseous products of its thermal decomposition.

Oil mist is formed both due to mechanical breaking of the cooling liquid flux into droplets (caused by rotation of the material being machined or of the tool) as well as to condensation of coolant vapours. The latter are produced at high temperature spots (e.g. a material-tool contact). According to WENDLER [28], the average sizes of mist droplets formed mechanically amount to 10 μm. The initial sizes of mist droplets resulting from the evaporation and

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subsequent condensation are of order of 10^{-3}–10^{-2} μm. Since, however, they form condensation nuclei, their sizes increase quickly up to 0.5–4 μm.

Oil concentrations in the ambient atmosphere around the grinders, autolathes, and other types of machine tools (milling machines, lathes, etc) amount to 2.8–97 mg/m³, 3.9–87.1 mg/m³ and 4.8–196.1 mg/m³, respectively [23].

Oil mist is a serious hazard for the workers' safety (slippery floors and holders) and above all for their healths because of its pathogenic effects. From the medical viewpoint [2] these effects have both local and general toxic character. About 8% of coolants is lost to the atmosphere in form of mist, vapours of oils and gaseous products of their thermal decomposition [23]. The loss increases the production cost.

2. REVIEW OF THE KNOWN METHODS OF OIL MIST REMOVAL FROM THE ATMOSPHERE

Fine-dispersed mist particles have been so far separated by filtration in porous materials and/or electrostatically. Preliminary separation of larger droplets (>10 μm) takes sometimes place in cyclons or simple plate separators.

Table lists the known methods of oil mist removal from the atmosphere, giving also their brief descriptions and the respective references. Considering the fact that gaseous pollutants of the air drawn off oil-cooled machine

Table

Methods of mist separation

Zestawienie metod separacji mgieł

Device	Destination	Droplets diameter	Effectiveness of separation	References
cyclons plate separators rotor separators ring packing	preliminary separation	$d_k > 10$ μm	$\eta > 90\%$	[5,6,14,19,25]
filters	final separation	0.1 μm $< d_k <$ 5 μm	$80\% < \eta \leqslant 100\%$	[3,4,9,16–18] [21,22,24,27]
electrofilters	final separation	0.1 μm $< d_k <$ 60 μm	$95\% < \eta \leqslant 100\%$	[16,29]
washers	final separation	–	$\eta > 90\%$	[1,7,8,12,13]

tools are mainly composed of hydrocarbons or their mixtures with steam (thus the substance totally or partially combustible), their noxious effects may be neutralized by: thermal combustion in open flame, cathalytic combustion and adsorption.

As yet, the combustion of oil vapours in the air drawn off the machine tools has not been applied, whereas the adsorption (which — considering oil recovery — seems to be not payable [21]) is employed only when low concentrations of highly toxic pollutants appear.

From the methods reviewed the following conclusions may be inferred:

1. So far only the oil mist, constituting liquid phase of pollutants, has been removed, and no methods were applied to remove the products of gaseous evaporation and thermal decomposition of oils, the amount of which may be substantial.

2. Commonly applied methods are: multistage mist removal preceded by inertial separation of droplets, the diameters of which are larger than 10 μm, and the removal of smaller droplets (0.1–10 μm) by filtration through fibrous materials or by electrostatic separation. In both the methods the resulting mist concentrations may be lower than 5 mg/m^3.

3. Fiber filtres are more usually employed in mist removal than the electrostatic ones because of their lower cost, simpler construction and smaller overall dimensions. Energy price increase makes, however, electrostatic filters competitive owing to the much lower flow resistances (0.2–0.4 kPa) as compared to the fiber filters (2–5 up to 15 kPa).

4. The lack of commercial techniques for removal of oil vapours and oil thermal decomposition products — based on the thermal and catalytic combustion or absorption results, — most probably, from high costs of these processes involving a substantial amount of heat or expensive materials.

5. The mist removing sorption properties of various kinds of washers have not been utilized yet.

3. CONCEPT OF A NEW METHOD FOR OIL MIST SEPARATION

First experiments in which the oil vapours and mist were removed from air by means of washers [1] are very promising. It may be expected that the methods of wet separation will find a wide application. To this end, however, the type and adaptation of the adequate systems as well as suitable working liquids (for a simultaneous mist removal and the possible sorption of gaseous pollutants) are required. It seems that a highly efficient separation of oil mist particles may be achieved by employing washers, characterized by a fine dispersion of working liquid and high flow rates of the purified gas. These conditions promote the coalescence processes. It seems highly probable that submicrone oil droplets (10^{-1}–10 μm), after being introduced into the flux of working liquid droplets (the sizes of the latter being much greater and of order of 10^2 μm), may be subject to coalescence due to substantial differences between their relative velocities (effect of inertial collisions) and due to diffusion. The agglomerations formed in this way, the dimensions of which are of order of those of working liquid droplets (10^2 μm), could be separated in a conventional drop separator. The above processes might be, among others, realized in high-speed washers which comprise also injection contactors. The operation principle of the injection contactor is explained in fig. 1.

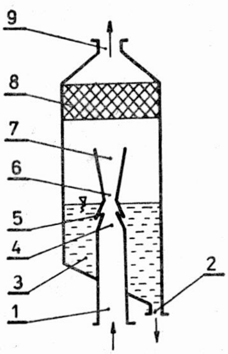

Fig. 1. Structure and operation principle of injection contactor with self-acting circulation of liquid

1 – inlet connecting pipe, *2* – outlet connecting pipe, *3* – working liquid, *4* – confusor, *5* – gap, *6* – contactor choke, *7* – diffuser, *8* – demister, *9* – outlet connecting pipe

Rys. 1. Schemat budowy i zasada działania iniekcyjnego kontaktora z samoczynnym obiegiem cieczy

1 – króciec wlotowy, *2* – króciec spustowy, *3* – ciecz robocza, *4* – konfuzor, *5* – szczelina, *6* – gardziel kontaktorta, *7* – dyfuzor, *8* – odkraplacz, *9* – króciec wylotowy

The design proposed is characterized by nozzless desintegration of the working liquid circulating spontaneously in a closed cycle. Nozzless desintegration of the working liquid is applied to increase the operational reliability of a future industrial installation, even if the circulating liquid gets polluted with mechanical impurities, which cannot be excluded. The self-acting cycle (i.e. without circulating pumps) based on the pressure difference produced in the injection contactor, on gas-liquid friction and gravity forces is to serve the same purpose.

4. TEST STAND

In order to verify the outlined concept of oil mist separation, a test stand has been designed and constructed. Its scheme is shown in fig. 2. Air taken from the interior of laboratory hall was introduced into a pipeline *1*. An orifice *2* was mounted to measure the flow intensity of the simulated aerosol. Test aerosol was obtained by introducing oil mist generated in generator *3* into the pipeline *1*. Aerosol prepared in this way (air polluted with oil mist and vapours) is directed to the inlet of the injection contactor *5*. After having left the contactor, the air, containing also fine droplets of the working liquid, flows through the condenser *6* (composed of a metal gauze) and the condenser *7* (Białecki' s rings), where the ultimate separation of the working liquid droplets takes place. The separated liquid flows gravitationally to the storage tank *8*. After the measuring cycle is performed the liquid flows down gravitationally to the measuring

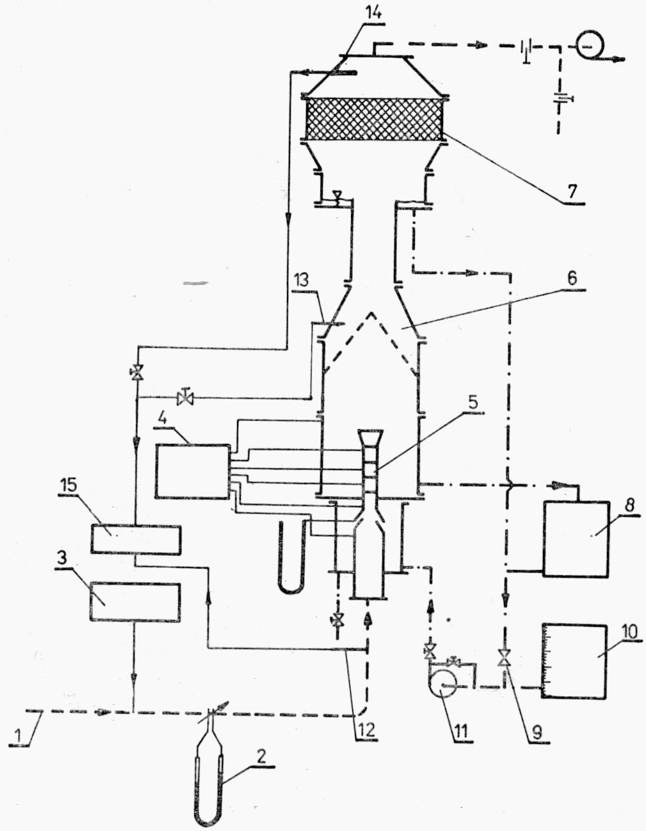

Fig. 2. Test stand for investigations of oil mist separation in injection contactor
Rys. 2. Schemat stanowiska do badań separacji mgieł olejowych w iniekcyjnym kontaktorze

tank *10* through the valve *9*. During the measuring cycle this valve is closed. In this way, while pumping the liquid with the pump *11* to feed the contactor, one may determine the intensity of working liquid flow through the contactor. Stub pipes *12*, *13* and *14* are used for sampling the purified air and directing it to the optical analyser of oil mist concentration *15*. Pressure drops between the separate cross-sections of the contactor are measured by means of a battery of manometers 4.

5. MEASUREMENT OF THE CONCENTRATION OF OIL-MIST IN ATMOSPHERE

The concentration of oil mist in atmosphere was measured nephelometrically using a nephelometer FEN [10, 11]. This method may be used if the indications of the instrument were previously calibrated. Scheme shown in fig. 3 illustrates the measuring system used for calibration of the nephelometer as well as for the measurements of oil mist concentrations. A sample of oil mist containing air transported by the pipeline *1* is taken by the probe *2* and then directed to the nephelometer *3*. The flow of gas sample through the cell of the nephelometer results in the scattering of light flux, corresponding to the concentrations of oil mist present in the sample. The so-called "torch" formed by

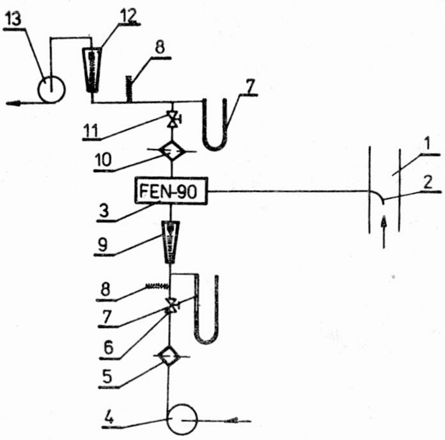

Fig. 3. Measuring system for oil mist concentration in atmosphere and calibration of a nephelometer FEN 90

Rys. 3. Schemat układu do pomiaru stężenia mgły olejowej w powietrzu oraz wzorcowania nefelometru FEN 90

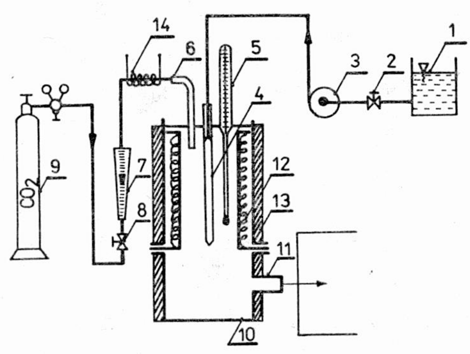

Fig. 4. System of oil mist generation

Rys. 4. Schemat układu generowania mgły olejowej

the oil droplets on the optical path of nephelometer is washed by an optically pure side-air in order to form a flux of "torch" and to avoid the sedimentation of oil on the optical elements of the apparatus. The intensities of sample and side-air sample flows amount to 3.9×10^{-4} and 5.6×10^{-4} m^3/s, respectively. The system supplying side-air consists of pump *4*, preliminary filter *5* (purifying side-air), control valve *6*, manometer *7*, thermometer *8*, and rotameter *9*.

The mixed fluxes of test-and side-air are carried away from the nephelometer by a common pipe through the filter *10**, control valve *11*, rotmeter *12*, and pump 13.

While adapting the above described method of determining the concentrations of oil mist in atmosphere, it has been stated that the results obtained depend on the way and quickness of aerosol sampling. Although the oil mist particles are of submicron sizes and should behave like a gas, it was, however, necessary to take the aerosol samples by a probe at isokinetic velocities.

Nephelometer FEN 90 makes it also possible to determine the degree of oil mist dispersion by measuring the so-called polarization defect of scattered light as the ratio of scattered light intensities measured in two mutually perpendicular polarization planes (positions of polarizers). This method requires, however, a previous calibration of the apparatus by an indirect method in order to find the function:

$$\Delta = f(d)$$

where:

Δ – polarization defect,

d – average diameter of aerosol particles.

In the experiment discussed this procedure is not necessary, as in this case it is sufficiently enough to measure the degree of aerosol dispersion or to state whether such changes occur, since this provides the information about the stability of the generated aerosol parameters.

The so-called Kijeńska's method of determining the concentration of oil mist in atmosphere recommended by *Polish Standards* [20] has been rejected in the present work because of a number of shortcomings, namely:

long time of measurements (20 min),

the average efficiency of mist separation in sorption system (stated by the nephelometric method) amounts scarcely to 70%.,

high sensibility of the method to disturbing factors that implies a number of limitations.

For example, spectral analysis of the solution suggests the application of spectrally pure solvent. Hence, handling the preparation of sampling set-up must be performed extremely thoroughly, special attention should be paid to the elimination of any contact between the solvent and substances which may give a peak in the CH band. This refers also to materials of which the measuring system is constructed.

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*During calibration it performs the role of measuring filter equipped with unwoven cloth FPP on the filter paper FILTRAK, and during nephelometric measurements – the role of a filter preventing the oiling of the remaining part of the system.

Summing up, it should be stated that the absorption-spectrographic method for determining the concentrations of oil mists in atmosphere, recommended by the standard, is to a great degree imperfect. The above imperfectnesses are eliminated by the applied nephelometric method.

6. OIL MIST, ITS GENERATION AND PROPORTIONING

In order to generate aerosol formed by evaporation of oil coolants during mechanical working, a generating system, shown in fig. 4, has been constructed.

This system consists of generator *10* made of a steel pipe with a heating coil *12* wound around it. The lower part of the generator consists of a tank for condensate with a connector pipe *11* for proportioning the oil mist. The whole is insulated thermally with asbestos coating *13*. The power of heating coil may be regulated, hence different temperatures of oil mist generation may be obtained. The generation process runs on the surface of a steel rod *4* which is screwed into the upper deck of the generator. After the temperature of the process is set, the oil is pumped by the perystaltic pump *3* into the generator and flows out through the openings in the upper part of the rod *4* onto its surface, flowing down in form of a film. The amount of the proportioned oil taken from the tank *1* is regulated by the valve *2*. The generator is also fed with CO_2 supplied from the bottle *9* through the control valve *8*, rotameter *7*, and inlet connecting pipe *6*. The proportioned CO_2 is preliminarily heated by heating elements *14*. The CO_2 is proportioned in order to create non-combustible atmosphere, as well as to force the outflow of the oil generated into the pipeline *1* in fig. 2. The intensity of oil mist outflow from the connecting pipe *11* (fig. 4) as well as its concentration in air flowing into the experimental contactor depend on the amount of CO_2 fed to the generator. The temperature of the process is measured with the thermometer *5*.

Construction of an original oil mist generator appeared to be necessary, following the analysis of the so far applied generators of submicron aerosols [15] as well as the experiences gained from the operation of oil mist generator built in the Military Institute of Chemistry and Radiation in Rembertów near Warsaw. The existing generators proved to be of no use for our experiments because of the following reasons:

sintering of oil on heating elements,

insufficient — with respect to the necessary ($\sim 5.6 \times 10^{-5}$ kg oil mist/s) — efficiency of the generator.

The preliminary works on the prototype have shown that a two-position control of temperature in generator is nonadmissible. The automatic system applied initially controlled the temperature within ± 20 deg. As it follows from fig. 5 such a character of temperature variations strongly influences both the value of concentration and the size distribution of the generated oil mist. A good thermal insulation, proportioning of CO_2 and temperature stabilization

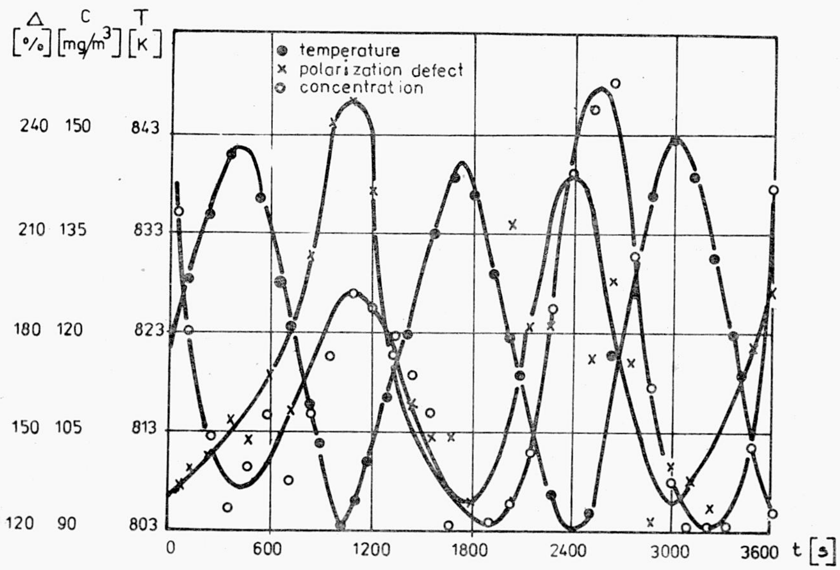

Fig. 5. The runs of working parameters of generator in the primary version

Rys. 5. Przebiegi parametrów pracy generatora w wersji pierwotnej

on the level $T \pm 2$ deg have allowed us to obtain a good operation of our generator. By this we mean that the concentration, efficiency and dispersion of oil mist particles are maintained at the desired level.

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BADANIA SEPARACJI MGŁY OLEJOWEJ W KONTAKTORZE INIEKCYJNYM CZĘŚĆ I. NOWA KONCEPCJA PROCESU SEPARACJI I PROJEKT EKSPERYMENTU

Opisano znane dotychczas metody wydzielania mgły olejowej z powietrza zanieczyszczonego w czasie pracy obrabiarek. Przedstawiono nową koncepcję procesu separacji w kontaktorze iniekcyjnym z samoczynnym obiegiem cieczy. Zaprezentowano doświadczalną instalację do badań tego procesu oraz metody pomiaru stężenia mgły. Przedstawiono nową konstrukcję generatora mgły olejowej i scharakteryzowano parametry jego pracy.

UNTERSUCHUNGEN DER ÖLNEBELSEPARATION IM INJEKTORKONTAKTOR TEIL I. NEUE KONZEPTION DES SEPARATIONSPROZESSES SOWIE EIN UNTERSUCHSPROJEKT

Es wurden die bisher bekannten Methoden der Ölnebelausscheidung aus der verschmutzen Luft während des Betriebs der Werkzeugmaschinen beschrieben. Es wurde eine neue Auffassung des Separationsprozesses im Injektorkontaktor mit selbsttätigem Flüssigkeitsumlauf dargestellt. Es wurde eine Untersuchungsanlage zur Prozeßprüfung sowie die Messmethoden der Ölnebelkonzentration vorgelegt. Man stellte eine neue Konstruktion des Ölnebelgenerators vor und seine Betriebsparameter wurden charakterisiert.

ИССЛЕДОВАНИЯ СЕПАРАЦИИ МАСЛЯНОГО ТУМАНА В ИНЪЕКЦИОННОМ КОНТАКТОРЕ ЧАСТЬ I. НОВАЯ КОНЦЕПЦИЯ ПРОЦЕССА СЕПАРАЦИИ И ПРОЕКТ ЭКСПЕРИМЕНТА

Описаны известные до сих пор методы выделения масляного тумана из воздуха, загрязнённого во время работы станков. Представлена новая концепция процесса сепарации в инъекционном контакторе с самодействующей циркуляцией жидкости. Показана экспериментальная установка для изучения этого процесса и представлены методы измерения концентрации тумана. Изображена также новая конструкция генератора масляного тумана и охарактеризованы параметры его работы.