History of aerosol research in Siberia

K.P. Koutsenogii

*Institute of Chemical Kinetics and Combustion,
Siberian Branch of the Russian Academy of Sciences, Novosibirsk*

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The main stages in the development of Siberian Branch of the Russian Academy of Sciences from its foundation in the late 50's until now are briefly reviewed. The state of aerosol researches in Siberia is considered and analyzed in comparison with the current world level in this field. It is shown that fast development of a new field is connected with peculiarities of research in the Siberian Branch. The aerosol studies that have been being conducted at the Institute of Chemical Kinetics and Combustion are considered as an example.

For better understanding of the current state of aerosol research in Siberia, it is very important to go back to the time of foundation of Siberian Branch of the Academy of Sciences of the USSR. Organization of the Siberian Branch and its further development determined, to a large degree, the nowadays level of the aerosol studies.

So, what happened in late 1950's?

Chronicle of foundation of the Siberian Branch

On May 18, 1957 the Soviet of Ministers of the USSR approved a Decree on the Organization of Siberian Branch of the Academy of Sciences of the USSR.

On June 7, 1957 the Presidium of the Academy of Sciences of the USSR considered the Decree and made a decision to organize Akademgorodok in Novosibirsk with 10 institutes in mechanical-mathematical, physical-technical, biological, geophysical sciences, and in economy.

On June 21, 1957 three chemical institutes more were included into the list.

On November 29, 1957 the Presidium decided to organize the East-Siberian Center of the SB RAS in Irkutsk in the period from 1958 to 1965. This center consisted of eight institutes in physical-chemical, geophysical, biological, chemical sciences, and geography.

In December, 1960 the place for building up Akademgorodok was chosen near Krasnoyarsk.[1]

The Siberian Branch had three main purposes:

1. Development of complex researches in basic and applied sciences connected with the development of Siberian region.

2. Strengthening of relations with the intensely developed industry and agriculture in the Eastern part of the USSR.

3. Active development of higher education to provide research institutes and various industries with highly qualified specialists.

In this connection, on January 9, 1958 the Soviet of Ministers of the USSR approved the decree on organization of Novosibirsk State University as a part of the Siberian Branch. Already in September of 1959 the University opened its doors for students, and in 1963 first specialists graduated from it.

These imposing decisions in the history of science of the USSR were caused by the objective reasons (Tables 1 and 2).

From Table 1 it is seen that Siberia had 75% of fuel resources (coal, oil, gas) of the former USSR. Besides, almost a half of waterpower resources and industrial wood, up to 20% of land resources, 10% of productive assets, and 8.5% of the human resources were concentrated in Siberia at that time.

Table 1. Distribution of power and mineral resources of Russia (Ref. 2)

Resource	Siberia/Russia ratio, in %
Coal, oil, gas	75
Waterpower resources	50
Industrial wood	50
Water resources	50
Land resources	20
Human resources	8.5
Productive assets	10

From Table 2 it is seen that Siberia occupies the area of 10 mln. km^2, what is equal to the territory of Europe and roughly a half of the territory of the former USSR. At the same time, the population density in Siberia was 3.6 times lower than the mean population density in Russia and almost 30 times lower than that in Europe.

It can be easily understood that the future of Russia heavily depends on the rate of development of Siberian resources. It is clear that the problems in industry, agriculture, and management of this vast territory could not be solved without invoking modern technologies. However, to do this, a network of research institutes ought to be organized in the Siberian region.

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Table 2. Density of population in different regions

Territory	Population, mln.	Area, mln. km^2	Ratio	
			Area	Population density
Europe	728	10.5	1.05	30.3
Russia	148	17	1.7	3.6
Siberia	24	10	1	1

As the passed years showed, the decisions made in 1957 were right, and their implementation actually became an outstanding achievement of not only scientists, but all Russian people as well.

In June of 1959 the first institute, namely, the Institute for Hydrodynamics was built. In August of 1964 the Novosibirsk Center was formed. It included 15 institutes, a plant, and a living infrastructure.

By early 80's, a network of scientific centers and affiliates of the Siberian Branch of the AS USSR was created all over Siberia.[2] Simultaneously, the system of higher education was developed on the basis of scientific centers.

Similarly to the Academy of Sciences, the Siberian Branches of the Agricultural Academy of Sciences and the Medical Academy were organized in Siberia.

In the early 90's, the complex system of scientific and educational centers had been formed.[3] Such big Siberian cities as Tyumen, Novosibirsk, Kemerovo, Krasnoyarsk, and Irkutsk hosted institutes of all the three academies, universities, and international research centers. Besides, research and development institutes were organized all over Siberia. This system forms a powerful scientific potential of Siberia.

Aerosol research in Siberia

The development of multidisciplinary complex researches in Siberia certainly was the main factor that stimulated harmonious development of all research fields, including aerosol studies. Data presented in Table 3 support this statement. Table 3 lists the names of research institutes and higher education institutions, in which the research into different branches of aerosol science are being conducted. They are classified according to the subject actively discussed at the last European Aerosol Conference in Edinburgh (September, 1998).[4] It is seen from Table 3 that now aerosol researches are performed at 22 institutes of the SB RAS, three institutes for applied studies, and at seven universities.

In the Novosibirsk Federal Center, the Institute of Aerobiology was organized, whose main subject is bioaerosol. In the entire combination, the aerosol researches in Siberia fully cover the main fields of aerosol science.

As seen from Table 3, the Institute of Chemical Kinetics and Combustion SB RAS conducts most complex aerosol research. In this institute, the aerosol studies make up one of the main subjects, and several laboratories are engaged in these studies.

The Institute of Atmospheric Optics SB RAS in Tomsk also is a large institute, in which aerosol studies are among the main subjects of the research activity. Now this institute is recognized in Russia as one of the leaders in atmospheric studies.[5]

Since the development of many new research fields in the SB RAS has much in common, let us dwell on the development of aerosol science at the Institute of Chemical Kinetics and Combustion (IChKC).

On June 28, 1957 the Presidium of the Academy of Sciences of the USSR approved the Charter of the SB AS USSR and the main directions of the research at its institutes.

The main research directions for the IChKC were the following:

– study of elementary chemical reactions, especially, reactions with participation of free radicals, and the development of the corresponding physical and radiospectroscopic methods;

– field studies of physical chemistry of combustion and **physical chemistry of disperse systems**;

– synthesis and study of highly saturated compounds.

Initially, the studies of disperse systems were thought to be connected with the study of the dispersal mechanism at combustion of solid fuel. However, the actual situation changed somewhat the priorities, because the subjects of scientific research were determined in connection with the problems in the development of Siberian region.

One of the most urgent problems in Siberia is gnat that is very unpleasant for people and animals. That is why on January 12, 1961 the Presidium of the SB AS USSR approved the Program "Application of new technical means for gnat control over large areas." According to this Program, the IChKC started the research on the development of a powerful aerosol generator (headed by A.A. Kovalskii).

The experiments on the use of aerosols for protection against insects developed into large-scale studies aimed at creation of the optimal aerosol technology for application of biologically active substances. The research in this area is being successfully conducted now, as well.

In 1971 the specialized Laboratory of Disperse Systems was organized at the IChKC. The research area of this laboratory included development of the aerosol technology for the insect control and study of dispersal processes at combustion of solid fuel.

Table 4 lists some stages in the aerosol research at the Laboratory of Disperse Systems for the period from 1961 to 1999. The purposes, terms, and most important results of the works are also given in the Table.

Let us return to the history of studies on the optimal aerosol technology of vegetation protection.

Table 3. Aerosol researches at Siberian institutes and universities

Institution	City	Founded in	Aerosol research
Institutes of the Academy of Sciences			
Institute of Computational Mathematics and Mathematical Geophysics	Novosibirsk	1963	● ○ ■
Institute of Computer Technologies	»	1990	● ○
Institute of Heat Physics	»	1957	● ■ □ ▲
Institute of Theoretical and Applied Mechanics	»	1957	● ■ □ ▲
Institute of Hydrodynamics	»	1957	● ■ □ ▲
Institute of Catalysis	»	1958	● ○ ■ □
Institute of Organic Chemistry	»	1958	■
Institute of Ecological Instrument Engineering	»	1986	■
Institute of Chemical Kinetics and Combustion	»	1957	● ○ ■ □ ▲ △
Institute of Solid Body and Mechanical Chemistry	»	1957	▲
Institute of Animal Systematics and Ecology	»	1957	● △
Institute of Nuclear Physics	»	1957	■
Institute of Cytology and Genetics	»	1957	△
Limnological Institute	Irkuts	1961	● ○
Institute of Atmospheric Optics	Tomsk	1968	● ○ ■ □
Institute of Climate and Ecological Monitoring	»	1996	○ ■ □
Institute of Strength Physics and Materials	»	1984	● □ ▲
Institute for Water and Ecological Problems	Barnaul	1988	○
Institute of Coal	Kemerovo	1983	● ○
Institute of Forest	Krasnoyarsk	1958	○
Computer Center	»	1975	●
Applied research institutes			
Institute of Applied Physics	Novosibirsk	1967	■
Design Office of Power Engineering	»	1980	■
Institute of Aerobiology of Federal Center of Virology and Immunology	»	1994	● ○ □ △
Institutions of higher education			
Novosibirsk State University	Novosibirsk	1959	● ○ ■
Novosibirsk State Technical University	»	1948	● □
Siberian State Geodesic Academy	»	1933	■
Tomsk State University	Tomsk	1878	● ○ ■
Barnaul State University	Barnaul	1985	● ○ ■
Irkutsk State University	Irkutsk	1957	● ■
Kemerovo State University	Kemerovo	1978	● ○

N o t e . ● – basic research; ○ – atmospheric aerosols; ■ – measurement techniques and equipment; □ – applied research; ▲ – materials; △ – human health.

Table 4. Some stages of the aerosol research at the Laboratory of Disperse Systems of the IChKC

Problem	Terms	Purposes
Optimal aerosol technology of the vegetation protection	1961 – 1999	Development of aerosol technology for application of biologically active substances, which reduce consumption of these substances, environmental pollution, and ecological risk.
Formation of aerosols at combustion of solid fuel	1972 – 1978	Revealing of the dispersal mechanism at combustion of solid fuel.
Ice-forming aerosols for active actions on supercooled clouds and fogs	1973 – 1984	Search of the ways to enhance the efficiency of ice-forming compounds.
Gas cleaning from liquid aerosol particles	1974 – 1988	Development of efficient tools for gas cleaning from liquid aerosols in aircraft conditioning systems and obtaining of pure gases in oil compressors.
Creation of efficient masking aerosols in the IR region ($1 < \lambda < 30$ μm)	1986 – 1988	1. Determination of masking properties of aerosols with different particle size in the region from 0.5 to 30 μm. 2. Evaluation of the possibilities to improve the masking ability in the IR region for aerosols of thermo-mechanical generators.
Atmospheric aerosols	1974 – 1999	Study of the properties of atmospheric aerosols and their influence on the environment, human health, and climate.

Optimal aerosol technology of protection of wild and farm plants and human health since 1961 until now

From the very beginning, the works on development of new tools for gnat control were of complex character, which is characteristic of the activity in the SB AS.

The specialized design group at the IChKC created the powerful aerosol generator. Apart from the development of technical documentation, this group was responsible for fabrication of the generator and its testing under field conditions. Already in summer of 1961 the first research missions were conducted with the participation of entomologists from the Biological Institute, SB AS and the leading gnat control specialists from Moscow and Leningrad (St. Petersburg).

In addition to entomologists, who were responsible for evaluation of the efficiency of gnat extermination, veterinarians, ichthyologists, ornithologists, and hygienists took part in the missions. Their task was to evaluate possible risks for animals and human health.

To estimate the physical-chemical characteristics of an aerosol cloud, physicists from the Institute of Theoretical and Applied Mechanics SB AS took part in the studies. The participation of specialists from different fields provided the complex character of the investigation, and ecological problems were solved along with the technological estimation of the generator efficiency.

Although not all of the problems were solved in the first missions, the results obtained showed that at a proper aerosol treatment the range of efficient action of the aerosol cloud can be up to several kilometers. It became clear that, at such scales of the treatment, further improvement of the technique of field studies and numerical estimation of exterminated gnat at large distances is needed.

Already in the next mission of 1962 the problems of efficiency of the exterminating mosquitoes using a large aerosol cloud were mainly solved. However, this required development of specialized equipment for measuring the characteristics of the aerosol cloud and studying meteorological conditions, as well as for conducting field test remotely from a distance up to several kilometers from the source (Fig. 1). Actually, this equipment served a prototype for the further developed system of field physical-chemical laboratories and automated meteorological station (Figs. 2 and 3).

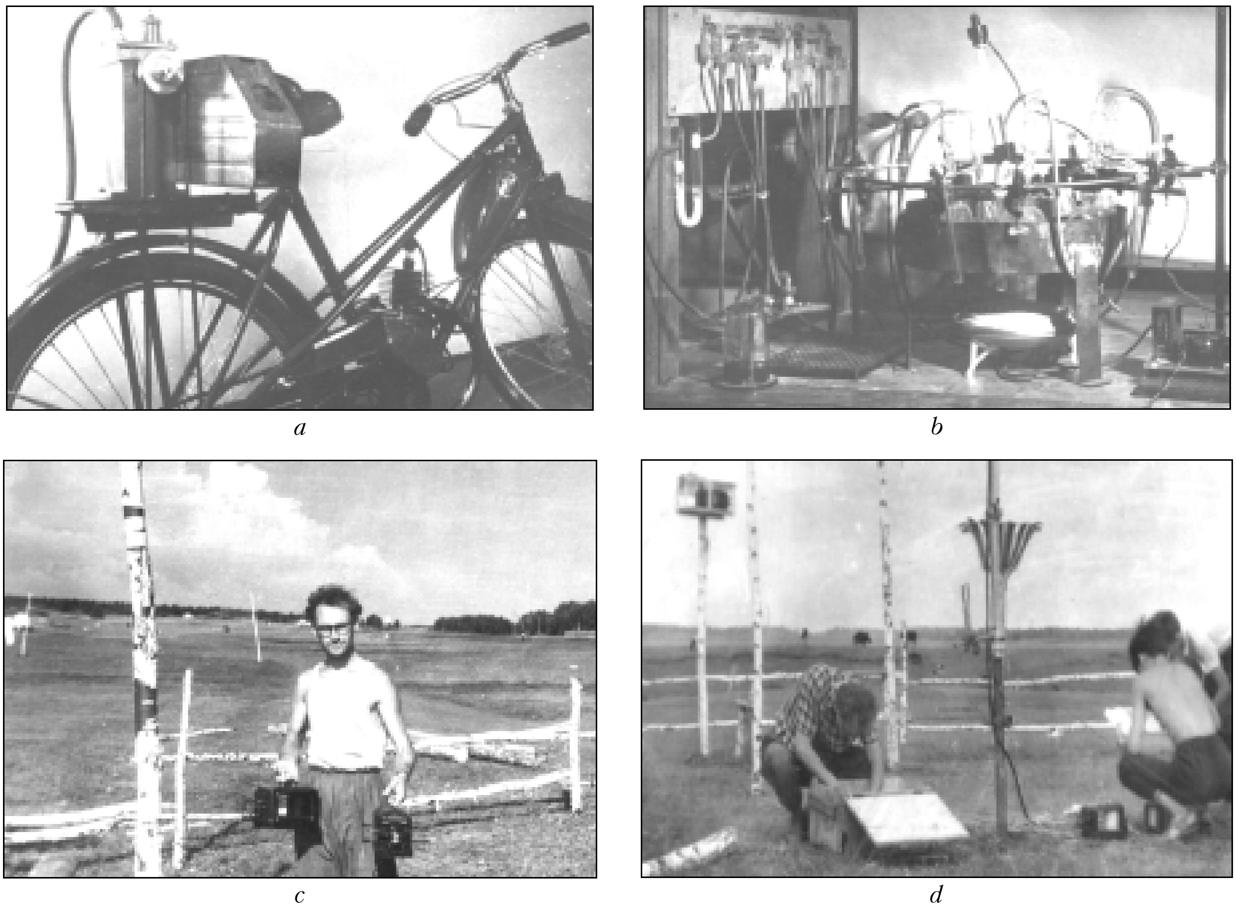


Fig. 1. Field equipment for physical-chemical studies in the mission of 1962: mobile physical laboratory (*a*); field chemical laboratory (*b*); field meteorological station (*c* and *d*).

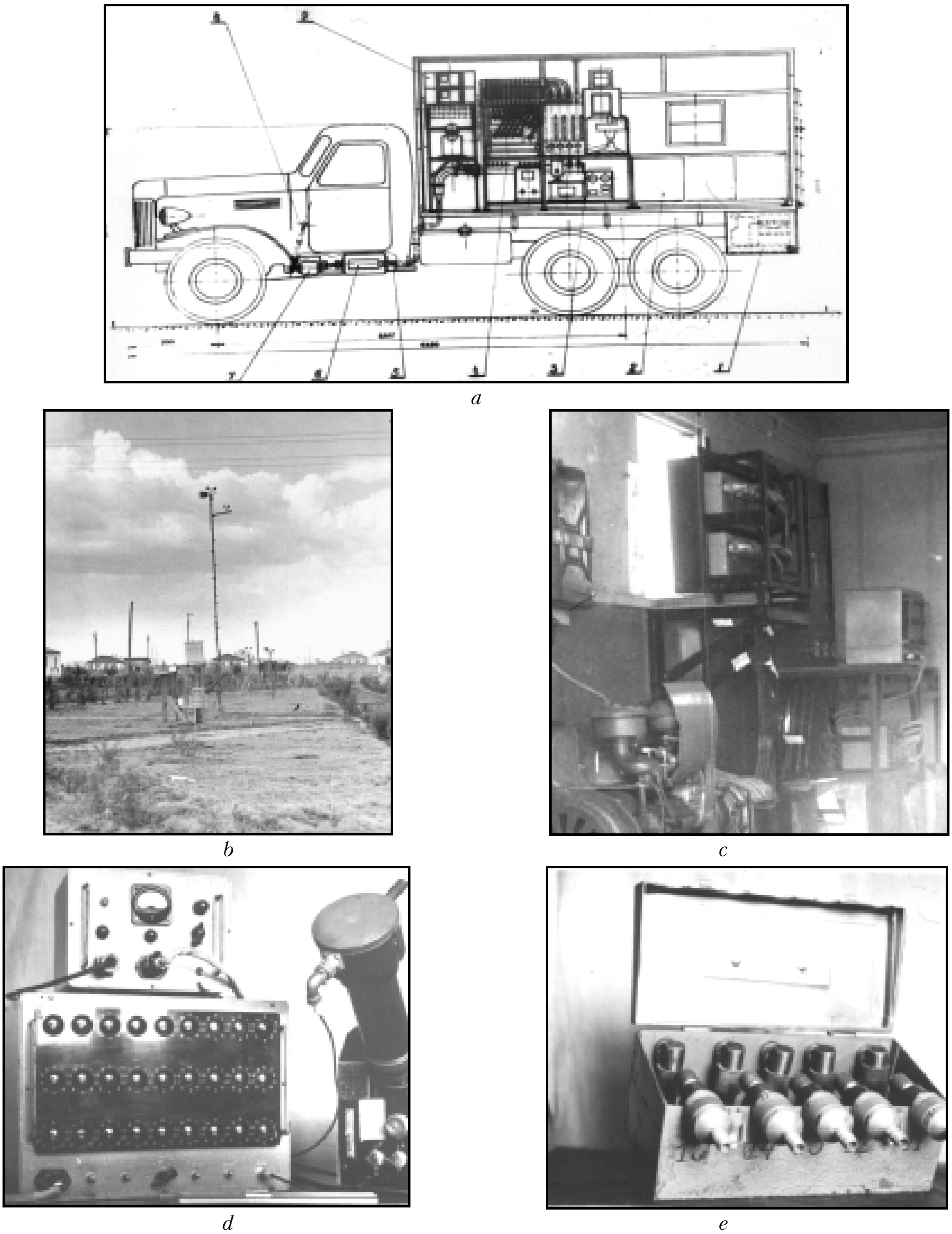
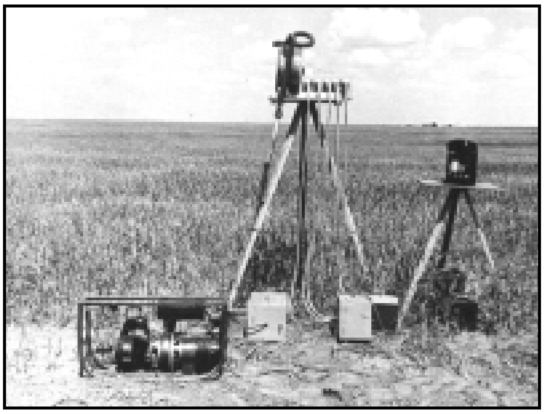


Fig. 2. Field equipment for studying the regularities of spread of the aerosol cloud in the mission of 1966: mobile physical laboratory (*a*); automated field meteorological station (*b*); arrangement of devices in the physical laboratory (*c*); 10-channel photoelectric counter of aerosol particles (*d*); battery of cascade impactors (*e*).

The works on the development of aerosol equipment, as well as its practical use can be divided into two periods. The first period (1961–1976) is associated with the development of powerful aerosol generator of the thermo-mechanical type (MAG). Its specifications and applications are given below. This generator is characterized by the bimodal size spectrum of the generated particles. Droplets formed at vapor condensation present one mode. These particles have a submicron size. The particles presenting the second mode arise at mechanical breakage of a solution by a hot gas jet and following evaporation. As a rule, these droplets are larger than 50 μm.

Specifications

Rate of aerosol formation	50 – 400 l/min
Size spectrum – bimodal	
condensation mode	$d < 1$ μm
mechanical mode	$d > 50$ μm
Types of pests:	
carriers of diseases	mosquitoes
forest pests – leaf and needle beetles	pine measuring worm moths, silkworm, cockchafer, etc.
agricultural pests	noctuid, locust
Used in	1 organization
Number of generators manufactured	4
Testing regions	Novosibirsk, Kurgan, Tyumen, Sverdlovsk, Chita regions, Altai Krai, Northern Kazakhstan
Total area protected	2 550 000 ha



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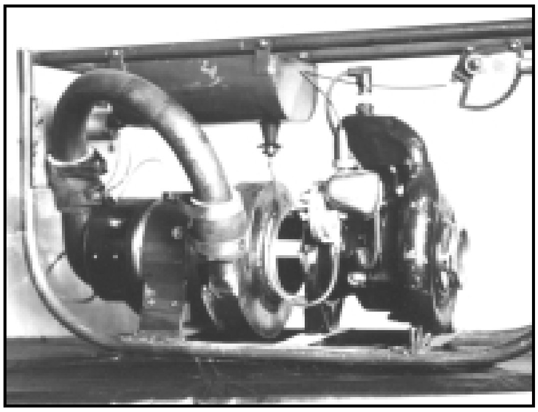

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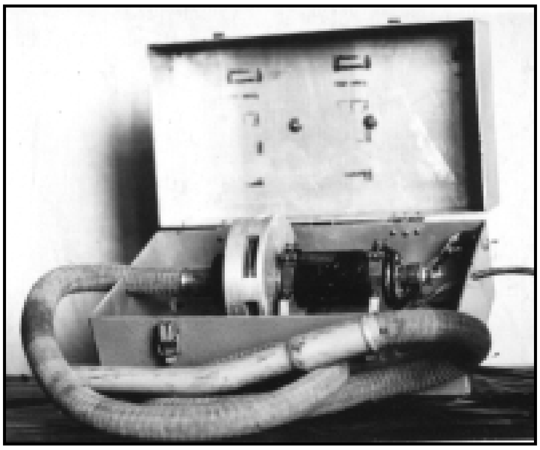

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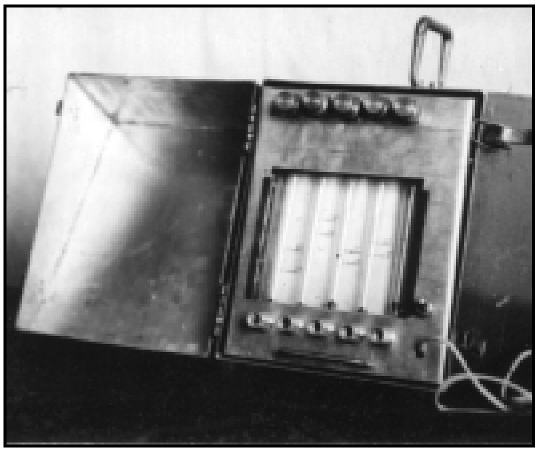


d

Fig. 3. Mobile field system (mission of 1966): field system for sampling and measuring the number concentration of aerosol particles during experiment (*a*); 3-kW field power supply for the measuring system (*b*); blast blower for aerosol sampling onto AFA-KhA filters (*c*); multichannel vacuum pump for sampling with the use of the battery of cascade impactors.

In 1963, first forest treatments against pests were conducted. They demonstrated high efficiency, and already in 1967 the Ministry of Forest of the Russian Federation created a specialized group equipped with two aerosol generators. From the very beginning, this group conducted protective measures against both forest pests and mosquitoes.

Thanks to the developed equipment, the bursts of forest pests in the Tyumen and Sverdlovsk regions, Altai Krai, and Mari Republic over the area of 1.4 mln. ha were liquidated.

In 1966 the aerosol generators were tested as applied to the fight with such agricultural pests as army worm and locust over the vast expanses of the Northern Kazakhstan. It turned out that the developed equipment has high productivity, efficiency, and wide applicability. As compared to usual methods, application of aerosols, as a rule, led to a significant decrease in the insecticide consumption.

Along with treatments, complex physical-chemical, biological, and sanitary-hygienic studies were conducted in order to determine the disperse and chemical composition of the aerosol cloud and regularities of its change while spreading, residual amounts in the environment, influence on various components of the entomofauna, and hazard to human health.

Many-year complex investigations revealed some principal factors that contradict the generally accepted ideas on the efficiency of the used technologies of insecticide application.

What is the cause for that essential change in the idea on the efficiency of insecticide application against pests?

By now it is thought that insects die either due to the contact with a poison deposited on the plant surface they creep on or by eating poisoned plants. It was believed that the amount of a preparation falling on an insect during treatment is insignificant. Our results contradict this statement:

1. High efficiency was observed at very low residual amounts in plants.

2. Direct experiments on contact of insects with plants sampled from treated areas showed that no more than 10–20% of insects died in this case, while in the filed experiments the efficiency of insect extermination was 90% and higher.

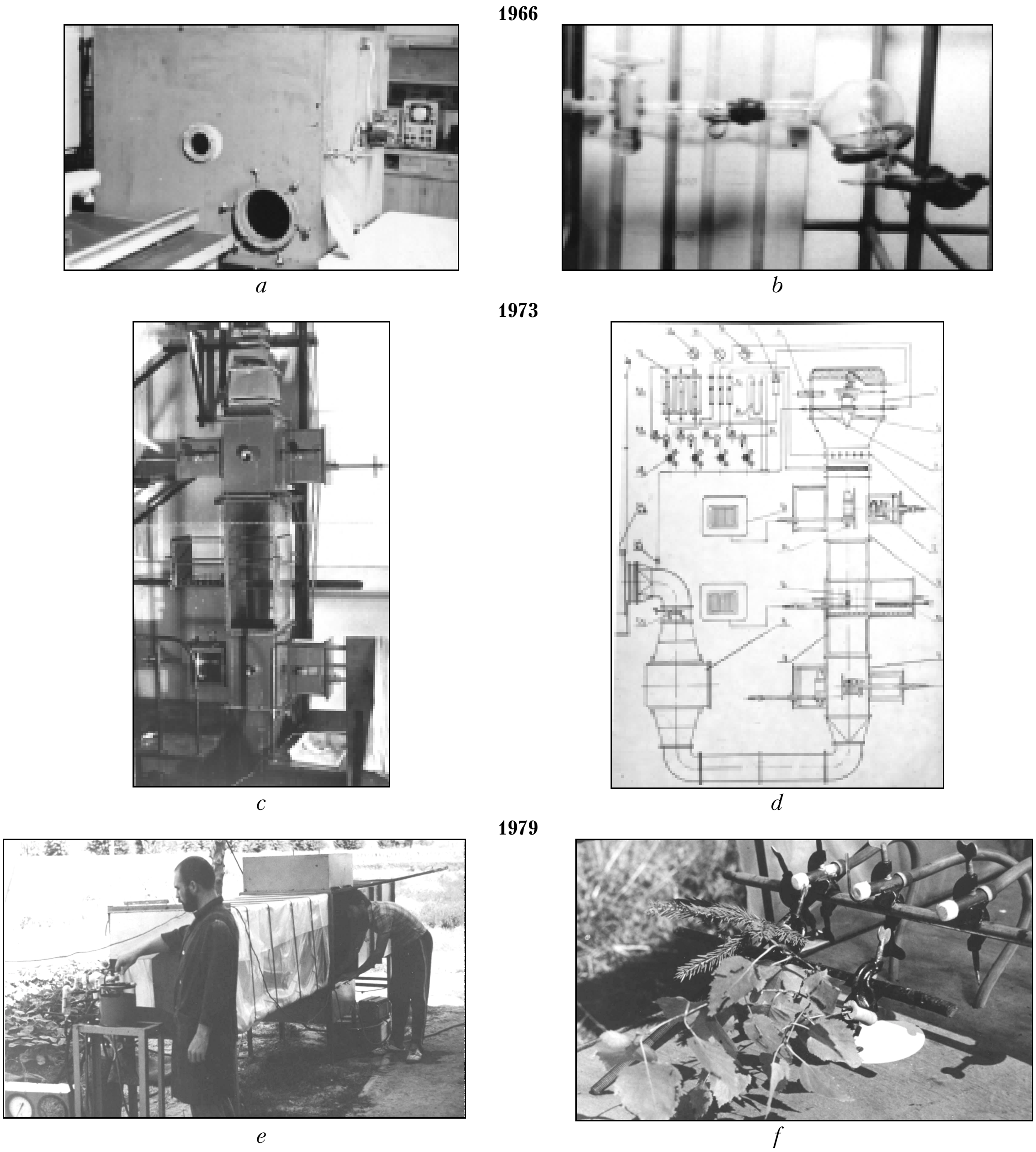


Fig. 4. Laboratory systems for studying aerosol sedimentation on plants and insects: static 1-m^3 aerosol chamber (*a*); laboratory generator of liquid aerosols (*b*); bench with vertical wind tunnel and generator of monodisperse aerosols (*c*); arrangement of devices on this bench (*d*); field horizontal wind tunnel with generator of monodisperse aerosols (*e*); interior view of the working section of the field system (*f*).

In this connection, in the early 70's special-purpose experiments were started to study the regularities of sedimentation of aerosol particles on insects and plants depending on the particle size and the air flow rate. For this purpose, stationary and field systems using monodisperse aerosols were developed.

Figures 4*c* and *d* show an example of a stationary system with a vertical flow-through channel, whose upper part houses a generator of monodisperse aerosols. Figure 4*e* shows a horizontal bench used in field experiments, and Fig. 4*f* shows the working chamber housing objects under study and devices measuring the characteristics of aerosol flow (rate, particle size and concentration).

In the experiments the following facts were revealed:

– insects die with the same probability no matter how they receive the lethal dose (from a flow, at contact with a poisoned surface, or topically)[6];

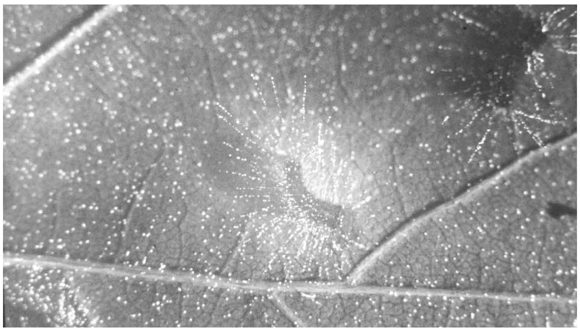
– at contact with the poisoned surface, the rate of preparation accumulation does not depend on the particle size, but depends on the sediment density and surface properties[7];

– as droplets are deposited on an insect, the preparation amount heavily depends on the particle size and flow rate.[8]

The last conclusion is illustrated by the experiments shown in Fig. 5. In Fig. 5*a* we see the sediment formed by particles 25 μm in diameter. It is seen that they are uniformly deposited on both insects and plants. Figure 5*b* shows the sediment formed by particles 11 μm in diameter. Now the amount of droplets deposited on caterpillars is significant, while that on the leaf surface the caterpillars are on is almost zero. The cross section of entrapment of different-size droplets by insects and plants was determined experimentally. Using the theoretical model of spread of the aerosol cloud, it was shown that there exists such a size at which much more preparation is deposited on an insect than on a plant, all other conditions are the same.[9]

This size is called optimal, and the technology, which provides generation of optimal-size particles is called the optimal aerosol technology.

The results of these fundamental investigations formed the basis for designing the aerosol generator with changeable particle size (GRD). This generator was created in 1978.



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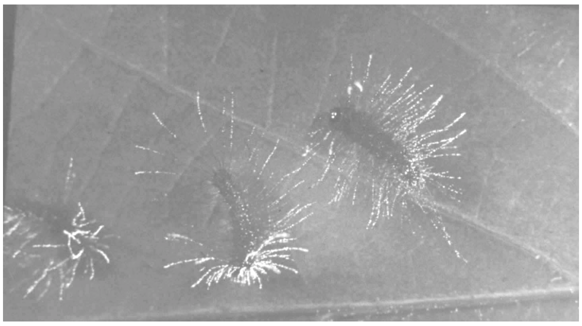

b

Fig. 5. Effect of droplet size on sedimentation on insects and plants: sediment of monodisperse droplets 25 μm in diameter (*a*); the same for droplets 11 μm in diameter (*b*).

This was the time of beginning of the second stage (1977–1999) in the development of optimal aerosol technology. This stage is associated with the creation of the generator of particles with changeable size. The main results obtained at this stage until now are presented below.

So, the development of new equipment and technologies allowed applications of the aerosol technology to the vegetation protection and pathogen control to be significantly extended.

Despite of the lower power of new modification of the aerosol generator, it is highly competitive with the previous modification in productivity. The variety of the used preparations is significantly expanded. The geographic regions, where the generator is successfully used, and the organizations using new equipment are greater in number.

Specifications

Rate of aerosol formation	1.0 – 30 l/min
Size spectrum – changeable	from 0.5 to 30 μm
Types of pests:	
carriers of diseases	mosquitoes
forest pests – leaf and needle beetles . .	more than 10 species
agricultural pests	a total of more than 30 species
pests in granary	–
pathogens in stock rooms	–
Used in	7 organizations (3 in Novosibirsk, 1 in Bashkortostan, 1 in Northern Kazakhstan, 1 in Southern Tadzhikistan, 1 in Yakutiya)
Number of made generators	26
Testing regions.	Novosibirsk and Orenburg regions, Bashkortostan, Altai Krai, Northern Kazakhstan, Southern Tadzhikistan, Yakutiya
Total protection area	1 500 000 ha

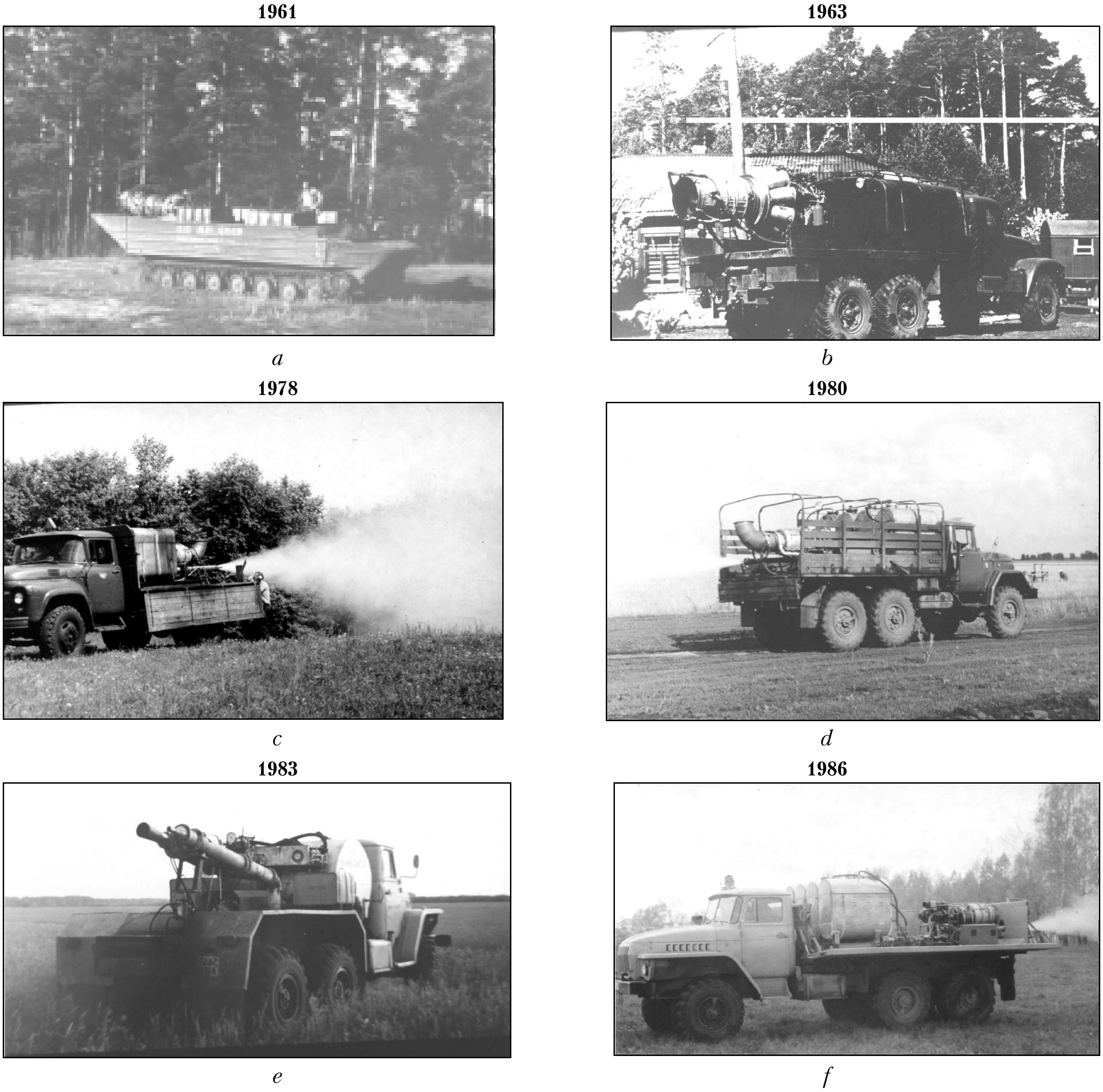

Fig. 6. Aerosol generators: MAG-1 (*a*); MAG-3 (*b*); GRD of different modifications (*c*, *d*, and *f*); aerosol generator of mechanic type developed in Lvov (*e*).

Figure 6 shows several modifications of aerosol generators developed and made with participation of the IChKC.

Now the aerosol research in Siberia covers all the important problems that are among most urgent ones for scientists throughout the world. Siberia is a unique region, and co-operation of Siberian scientists with their colleagues from foreign countries is mutually beneficial.

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