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DANGEROUS GOODS PANEL (DGP)

TWENTY-THIRD MEETING

Montréal, 11 to 21 October 2011

Agenda Item 6: Other business

SAFETY IN AIR TRANSPORT OF PACKAGES CONTAINING AN OXYGEN ENRICHED ATMOSPHERE

(Presented by A. Tusek)

SUMMARY

A request for guidance in the transport of live fish has been made in Australia by a company wishing to package live fish in 3000 L and 5000 L containers with an oxygen enriched atmosphere replacing air above the water level in the package.

Panel members are asked to consider the safety in air transport of large packages containing an oxygen enriched atmosphere and to offer their expert opinions.

Action by the DGP: The DGP is invited to discuss if a package containing an 'oxygen enriched atmosphere' is:

— safe for transport by aircraft; or
— should be classified as dangerous goods and included in the Technical Instruction; or
— should be regarded as 'forbidden' and included in the Technical Instructions.

1. INTRODUCTION

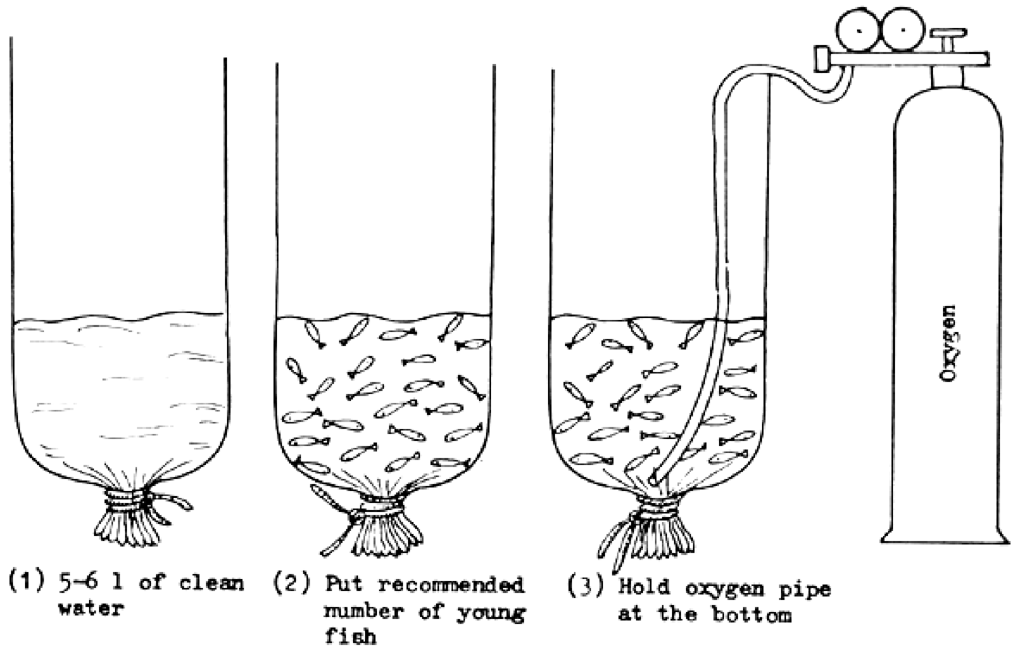
1.1 The Civil Aviation Safety Authority, Australia, has been approached by an exporter of live fish with a proposal to transport live fish in 3000 L and 5000 L moulded plastic containers.

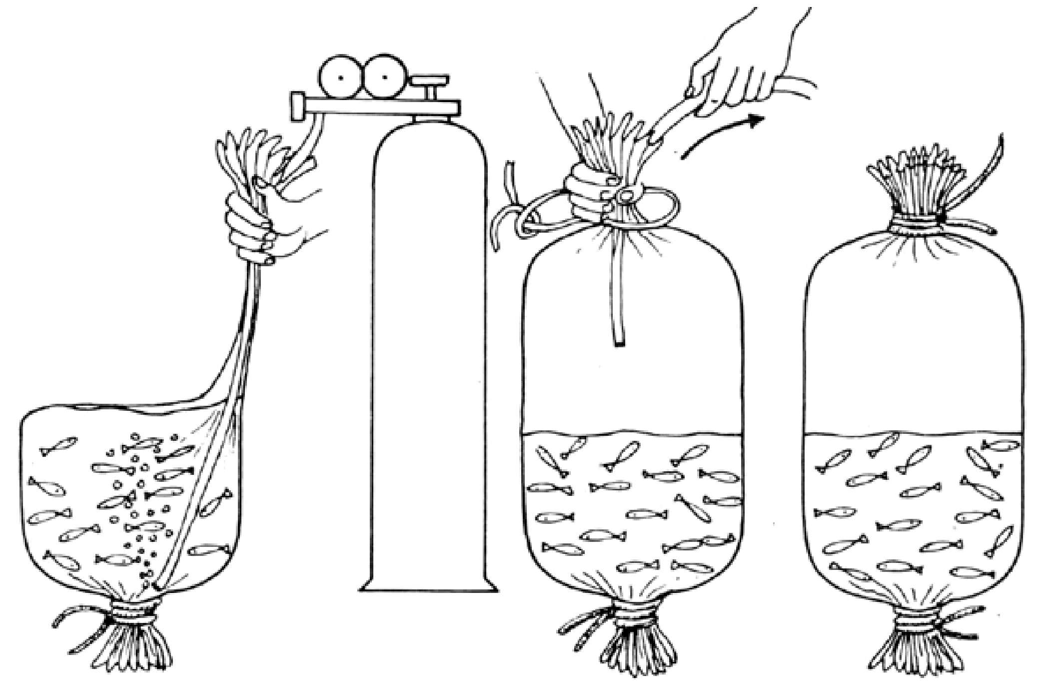
1.2 To enhance the survival of the fish during transport the company is intending to oxygenate the water carrying the fish and after closing the container, pure oxygen will be released into the container to replace oxygen in the space between the water level and the lid of the container.

1.3 Normal air contains 21% oxygen and levels above 23% are considered ‘oxygen enriched’ and in the method proposed to be used the result will be an oxygen level well in excess of 23%.

1.4 This packing method is not new and is contained in the IATA Live Animal Regulations with examples of using this method for the transport of tropical fish.

1.5 The main difference in the case presented is the volume of container and the volume of oxygen. The following diagram is from the European Inland Fishing Advisory Commission – Technical Paper 48 by R. Berka in 1986 and shows the method used for small packages. Attached for information.





(4) Press out air from inside and bubble oxygen through the water

(5) Blow extra oxygen to inflate the bag, remove the pipe and tie the bag tightly

(6) Bag ready to be transported

1.6 The system is explained as follows:

a) A 3000 L or 5000 L single wall polyethylene container will be part filled with oxygenated water.

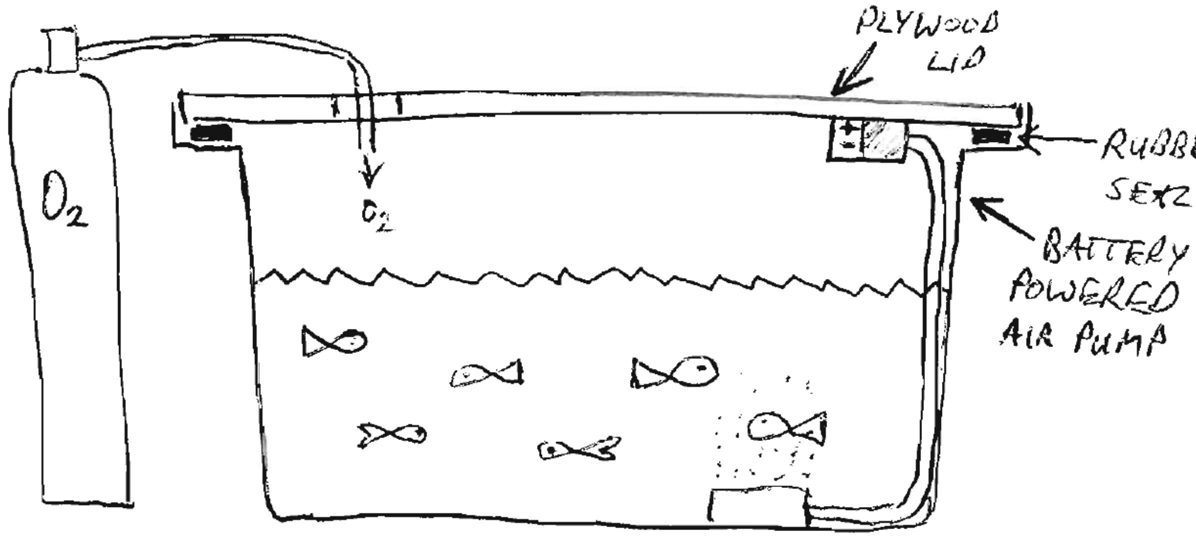
b) A rubber seal will be used in conjunction with a plywood lid that is screwed down.

c) Attached to the underside of the lid is a battery powered air pump that draws air from within the package and pumps it below the water line where it is bubbled through the water.

d) The plywood lid has a hatch that can be opened and oxygen is released into the package to displace as much air as possible. The hatch is then closed.

e) The closed package is then transported.

f)



1.7 Dangerous goods ‘forbidden’ for transport are those as follows; “Any article or substance which, as presented for transport, is liable to explode, dangerously react, produce a flame or dangerous evolution of heat or dangerous emission of toxic, corrosive or flammable gases or vapours under conditions normally encountered in transport must not be carried on aircraft under any circumstance”.

2. ACTION BY THE DGP

2.1 The DGP is invited to discuss if a package containing an ‘oxygen enriched atmosphere’ is:

a) — safe for transport by aircraft; or

b) — should be classified as dangerous goods and included in the Technical Instruction; or

c) — should be regarded as ‘forbidden’ and included in the Technical Instructions.

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APPENDIX A

AIGA

FIRE HAZARDS OF OXYGEN AND OXYGEN ENRICHED ATMOSPHERES

AIGA 005/04

Asia Industrial Gases Association

298 Tiong Bahru Road, #20-01 Central Plaza, Singapore 168730
Tel : +65 62760160 Fax : +65 62749379
Internet : http://www.asiaiga.org

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ASIA INDUSTRIAL GASES ASSOCIATION
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Acknowledgement

This document is adopted from the European Industrial Gases Association document IGC Doc 04/00/E 'Fire Hazards of Oxygen and Oxygen Enriched Atmospheres'. Acknowledgement and thanks are hereby given to EIGA for permission granted for the use of their document

Table of Contents

1 Scope

This document explains the fire hazards resulting from handling oxygen and the relevant protective measures.

2 Purpose

This document consists of three parts.

Part I, the actual document, is intended for line managers and supervisors. It provides the background to the subject and a description of the fire and explosion hazards associated with oxygen and oxygen enriched atmospheres.

Part II, designated as Appendix B, is a summary of Part I suitable to be produced as a pamphlet to be handed over to operators or as overhead slides.

Part III, designated as Appendix C, lists some accidents which have taken place in recent years and which can be used as examples underlining the hazards of oxygen and oxygen enriched atmospheres.

It is recommended that the document be used as the basis for training programmes.

3 Definitions

Oxygen in the sense of this document includes not only pure oxygen but all air mixtures containing more than 21 % oxygen.

4 General Properties

Oxygen, which is essential to life, is not flammable in itself, but supports and accelerates combustion. The normal concentration in the air which we breathe is approximately 21 % by volume.

4.1 Oxygen supports and accelerates combustion

Most materials burn fiercely in oxygen; the reaction could even be explosive.
As the oxygen concentration in air increases the potential fire risk increases.

4.2 Oxygen gives no warning

Oxygen is colourless, odourless and tasteless hence the presence of an oxygen enriched atmosphere cannot be detected by normal human senses. Oxygen also does not give any physiological effects which could alert personnel to the presence of oxygen enrichment.

Increasing the oxygen concentration of the air at atmospheric pressure does not constitute a significant health hazard.

4.3 Oxygen is heavier than air

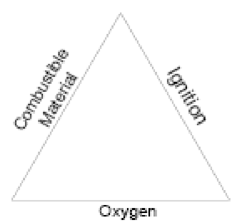
Being heavier than air, oxygen can accumulate in low lying areas such as pits, trenches or underground rooms. This is particularly relevant when liquid oxygen spills out. In that case the generated cold gaseous oxygen is three times heavier than air.

5 Fire hazards with oxygen

5.1 Necessary conditions for a fire

In general for a fire or explosion to occur three elements are required: combustible material, oxygen and an ignition source.

The "fire triangle" is the normal way of representing these conditions:



When one of the 3 elements is missing a fire cannot occur.

5.2 Oxygen

Oxygen reacts with most materials. The higher the oxygen concentration and pressure in the atmosphere or in an oxygen system then:

a) The more vigorously the combustion reaction or fire takes place;
b) the lower the ignition temperature and the ignition energy to get the combustion reaction started;
c) the higher the flame temperature and destructive capability of the flame.

Causes of oxygen fires can be categorised as follows:

d) oxygen enrichment of the atmosphere
e) improper use of oxygen

f) incorrect operation and maintenance of oxygen systems
g) use of materials incompatible with oxygen service

5.2.1 Oxygen enrichment of the atmosphere

Oxygen enrichment of the atmosphere can be the result of

a) Leaking pipe connections, flanges, etc. This can be particularly hazardous in areas where there is not sufficient ventilation causing the oxygen concentration to increase.
b) Breaking into systems under oxygen pressure.
A sudden release of oxygen under pressure can result in a relatively large jet of escaping oxygen. This may result in a torching fire.
c) Oxygen use in cutting and welding processes.
In processes such as cutting, gouging, scarfing and thermic lancing, oxygen is used, in quantities greater than necessary for the burning process. The unused oxygen remains in the atmosphere, and if ventilation is inadequate the air can become enriched with oxygen. Effective ventilation and periodic analysis for oxygen content is recommended.
d) Oxygen use in metallurgical processes. Incorrect practice in the use of blowpipes can also lead to oxygen enrichment, especially in confined spaces. Therefore care should be taken:
to follow correct hose purging and lighting up procedures,
to avoid delay in lighting the blowpipe after opening the valves,
to close the valves of the blowpipe and of the gas supply when interrupting or finishing the work,
to select the correct nozzles and pressures to maintain oxygen hoses leak-tight and periodically inspected.
e) Desorption.
Oxygen can be released in appreciable quantities when cold materials which have absorbed oxygen such as absorbents (molecular sieve, silica gel, etc.) or insulation materials are warmed to room temperature.
f) Cryogenic liquid spill.
A spill of liquid oxygen creates a dense cloud of oxygen enriched air when evaporating. In an open space hazardous oxygen concentration usually exists only within the visible cloud associated with the spill. Nevertheless, atmospheric checks should be carried out to confirm this when approaching the vicinity of the vapour cloud.
g) Liquefaction of air.
When using cryogenic gases with boiling points lower than oxygen, e.g. nitrogen, hydrogen and helium, oxygen enrichment can also occur.
Ambient air will condense on uninsulated equipment where the temperature is lower than the liquefaction temperature of air (approx –193 °C). This will also occur on pipework lagged with an open cell insulant. The liquid air so produced can contain up to 50 % oxygen and, if this liquid drips off and evaporates, the oxygen concentration in the last remaining portion can be over 80 %. Consequently, special precautions shall be taken with regard to the potential oxygen enriched insulation and to the vessel before starting repair work on any equipment.
h) Oxygen vents.
Particularly hazardous are areas where oxygen vents are located. A sudden release of oxygen can occur without warning. Note that the non-cryogenic production of oxygen or nitrogen might involve an occasional or continuous venting of oxygen.

5.2.2 Improper use of oxygen

Many serious accidents have been caused by the use of oxygen for applications for which it was not intended.

Examples of improper use of oxygen are:

a) Driving pneumatic tools
b) Inflating vehicle tires, rubber boats, etc.
c) Pressurising and purging systems
d) Replacing air or inert gas
e) Cooling or refreshing the air in confined spaces
f) A welder who intends to “cool” him/herself by blowing oxygen into his/her clothing
g) Dusting benches, machinery and clothing
h) Starting diesel engines

In each case the fire and explosive risk is the same and results from exposing combustible materials e.g. flammable gases, flammable solids, rubbers, textiles, oils and greases.

5.2.3 Incorrect operation and maintenance of oxygen equipment

Incorrect operation and maintenance of oxygen equipment is one of the most frequent causes of fires in oxygen systems.

Examples of Incorrect Operation

a) Failing to reset pressure regulators to the closed position when the oxygen cylinder valve has been closed. This results in extremely high oxygen gas velocities when pressurising the regulator next time it is used.
b) Rapidly opening valves. This can lead to ignitions caused by the heat generated by high velocity gas or adiabatic compression. Rapid opening of valves can result in momentarily high oxygen velocities, sufficient to project any debris being in the system through the system at sonic velocity causing frictional heat, sparks, etc. When the system is "dead ended" – as in the case with a pressure regulator connected to an oxygen cylinder – high heat can be generated through compression of the oxygen. Both these phenomena can cause a fire.
c) Opening a valve rapidly against a closed valve downstream in a system – this can lead to a similar situation as described above.
d) Start-up of oxygen compressor with oxygen should be performed according to the procedures described in the references No.5 and 6.

Examples of Incorrect maintenance

e) Working on pressurised systems.
f) Venting oxygen into confined spaces.
g) Allowing systems to become contaminated. Contamination by particulate matter, dust, sand, oils, greases or general atmospheric debris creates a potential fire hazard as highlighted above. Portable equipment is particularly susceptible to contamination and precautions shall be taken to prevent ingress of dirt, oil, etc.
h) Failure to completely remove cleaning solvents from components which are to be used in oxygen service. The solvent residues are not compatible with an oxygen enriched atmosphere.

5.2.4 Use of incorrect materials

Design of oxygen equipment is very complex and the why and how is not always obvious. In essence nearly all materials are combustible in oxygen. Safe equipment for oxygen service is achieved by careful selection of suitable materials or combination of materials and their use in a particular manner.

Any modifications to a design must be properly authorised to prevent incompatible materials being used.

Substituting materials which look similar is extremely dangerous and many accidents are reported where the cause was incompatible replacement parts. Examples of this practice could be

a) Replacing o-rings and gaskets with similar looking items. There are hundreds of different types of elastomer and most are not compatible with oxygen.
b) Replacing a metal alloy with a similar type of alloy. The composition of particular alloys has a significant effect on its mechanical properties and oxygen compatibility. "Bronze", which covers a wide range of alloys, has several varieties which are compatible with oxygen and even more which are not; e.g. tin bronze is used in liquid oxygen pumps while aluminium bronze is considered hazardous.
c) Replacing PTFE tape with a similar white tape. Not all white tape is PTFE and not all brands of PTFE tape are safe for use in oxygen.
d) Replacing parts/components with non-approved equipment is not allowed. The geometry of certain components is sometimes critical and approved manufacturer's parts shall always be used when maintaining oxygen equipment.
e) Replacing or installation of combustible material in filters e.g. plastics, paper, adhesives. Filters in oxygen systems are very sensitive to ignition due to presence of particles and complicated flow conditions. Therefore filters must be made of materials which demand very high ignition energy e.g. Monel.
f) Lubricants are generally not allowed in oxygen service except for special applications. Specialist expert advice shall always be obtained before applying such lubricants.

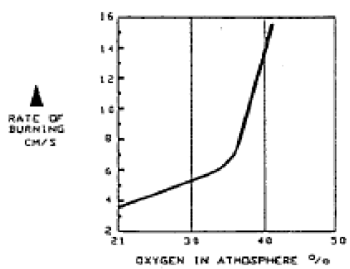
5.3 Combustible material

In oxygen enriched atmospheres

Materials that do not burn in air including fire resistant materials, can burn vigorously in oxygen enriched atmosphere or pure oxygen.

In enriched oxygen atmospheres the most common combustible material that directly affects safety of personnel is clothing. All clothing materials will burn fiercely in an oxygen enriched atmosphere. The same applies to plastics and elastomers.

An example of this increased reactivity can be seen below, for a cotton clothing material exposed to fire in atmospheres containing increasing levels of oxygen (Ref. No. 8).



Similar curves, indicating the same kind of behaviour could be drawn for other materials – in particular for plastics and elastomers.

In pressurised oxygen systems

In principle all organic materials will burn in oxygen and so do most of the metals and metal alloys. Pressure affects the behaviour of materials, e.g. by reducing ignition temperatures and increasing combustion rates. It is for these reasons that pressurised oxygen systems are only allowed to be constructed from materials and equipment whose design has been approved for the relevant operating conditions.

Oil and grease are particularly hazardous in the presence of oxygen as they can ignite extremely easily and burn with explosive violence. In oxygen equipment, oil and grease ignition often causes a chain reaction, which finally results in metal burning or melting. In such cases the molten or burned metal residue is projected away from the equipment and may be followed by an oxygen release. This in turn can lead to fierce and rapidly spreading flames in any adjacent combustible material external to the equipment. Oil and grease shall never be used to lubricate equipment that will be in contact with oxygen.

5.4 Ignition sources

In oxygen enriched atmospheres

Ignition sources in oxygen enriched conditions could be:

a) open fires or naked flames (cigarettes, welding or other hot work, sparks from internal combustion engines, furnaces etc.)
b) electrical sparks
c) grinding or frictional sparks

In pressurised oxygen systems

In systems containing oxygen under pressure the sources of ignition are not as obvious as naked flames and hot surfaces.

The following ignition sources have been identified as having caused fires in oxygen systems:

d) heating by adiabatic compression
e) friction
f) mechanical impact
g) electrical sparks
h) high gas velocity with presence of particles
i) heating by turbulence

6 Prevention of fires in oxygen systems

6.1 Information/training

Any personnel using oxygen equipment should be aware of the hazards. The minimum information that is required is shown in IGC Doc 23/00 "Safety training of employees" (adopted as AIGA 009/04).

All personnel should also have read the safety data sheet and safety information provided by the gas supplier.

For a greater insight into the hazards of oxygen with materials the following information is recommended:
(Note: IGC documents are under EIGA)

a) "Oxygen Pipeline Systems" IGC Doc 13/02
b) "Prevention of hose failures in high pressure gas systems" IGC Doc 42/89
c) "Reciprocating compressors for oxygen service. Code of practice" IGC Doc. 10/81
d) "Code of practice for the design and operation of centrifugal liquid oxygen pumps" IGC Doc 11/82
e) "Centrifugal compressors for oxygen service" Code of practice" IGC Doc. 27/93
f) SAG Info 15/97: "Safety principles of high pressure oxygen systems".
g) Flammability and sensitivity of materials in oxygen-enriched atmospheres –American Society for Testing & Materials (ASTM) symposium series
h) Cleaning of equipment for oxygen service. IGC Doc. 33/97 (adopted as AIGA 012/04)

All maintenance and repair work shall be performed by experienced and fully trained personnel.

All persons who work in areas where oxygen enrichment can occur shall be given adequate instructions as to the risks involved. Special attention shall be drawn to the insidious nature of the risks due to the rapidity of their effects. Practical training shall be given in the means by which such risks can be minimised, stressing the importance of identifying sources of oxygen enrichment and their isolation.

6.2 Proper design

In oxygen systems only equipment that has been specifically designed for oxygen shall be used, e.g. do not use nitrogen regulators in oxygen service. The proper design of equipment intended for oxygen service takes into account materials to be used and their configuration in order to minimise any risk of ignition. The reasons for a particular design and choice of material are not always obvious and expert advice shall be sought before considering a change of materials.

Oxygen equipment shall never be lubricated with oil or grease. For special well-defined cases a few special lubricants may be available. Specialist advice from the supplier shall always be sought.

Oxygen systems shall be designed in such a way, that the flow velocity is as low as possible. If the velocity is doubled the energy of a particle in the gas stream will increase four times.

6.3 Prevention of oxygen enrichment

6.3.1 Leak testing

Newly assembled equipment for oxygen service shall be thoroughly leak checked using air or nitrogen e.g. by timed gas pressure drop test, leak detection test (e.g. with approved leak spray or diluted soap solution) or other suitable methods. Periodic retests are recommended.

6.3.2 Operation and practice

When the work period is over the main oxygen supply valve shall be closed to avoid possible oxygen leakage when the equipment is not being used.

Filters, where fitted, shall not be removed to obtain higher flows. Filters should be inspected at frequent intervals and all debris removed.

6.3.3 Ventilation

Rooms where there is a risk of oxygen enrichment of the atmosphere shall be well ventilated. Examples of such rooms are:

a) filling stations
b) rooms in which oxygen vessels or cylinders are stored, handled, maintained, etc.
c) rooms in which oxygen is used or analysed
d) rooms for medical treatment with oxygen in hospitals, home care, etc.

In many cases natural ventilation can be sufficient e.g. in halls or rooms provided with ventilation openings. The openings should have a flow area greater than 1/100 of the room's floor area, be diagonally opposite each other and shall ensure a free air circulation with no obstructions. Where natural ventilation is not possible a ventilation unit, with a capacity of approx. 6 air changes/hour shall be provided. Special consideration shall be given to the ventilation of underground rooms, vessels, pits, ducts and trenches. There shall be a safety warning to indicate if the ventilation unit fails.

6.3.4 Vessel entry/ blanking procedures

Prior to entry into any vessel which is connected to a gas source other than air, the vessel shall be emptied, disconnected from such a source by the removal of a section of pipe, by the use of a spectacle plate or by inserting blind flanges and the space shall be thoroughly ventilated so as to maintain a normal atmosphere. Piping lock-out devices need to be documented in the Hazardous Work Permit. Reliance on the closure of valves to prevent oxygen enrichment is not sufficient. Permission to enter such a space subsequent to completing the steps indicated above shall be given only after the issue of an entry permit certificate signed by a responsible person. An analysis of the vessel atmosphere shall always be requested as part of the work permit requirements.

6.3.5 Isolation equipment

When an oxygen pipeline enters a building, an isolation valve shall be provided outside the building in an accessible position for operation. This valve and location shall be clearly marked and identified. The purpose is to be able to operate the valve in a safe location in the event of an oxygen release in the building.

Disused oxygen lines should be dismantled or completely severed and blanked off from the supply system.

6.4 Oxygen cleanliness

One of the fundamental safety procedures in preventing oxygen fires is to ensure that all equipment is properly cleaned before it is put into oxygen service. There are several methods whereby oxygen equipment can be cleaned which are outside the scope of this document. The IGC Doc. 33/97 "Cleaning of Equipment for Oxygen Service" covers this subject in detail. (adopted as AIGA 012/04)

Oxygen equipment also must be free of solid particles. In order to remove particles new oxygen equipment before start-up shall be purged with oil free air or nitrogen

6.5 Control of hot work

Any hot work which has to be performed close to any oxygen equipment or in an area where oxygen enrichment could occur, shall be controlled by a written permission (hot work permit) which is part of the work permit system. Hot work includes operations such as welding, brazing, drilling, grinding, etc.

7 Methods of oxygen detection

The method selected must offer a high degree of reliability of operation and be sufficiently sensitive to ensure warning is provided before a hazardous concentration of oxygen is reached. The normal method is through the use of an approved atmospheric monitoring instrument to confirm the effectiveness of the isolation and purging procedures prior to entry into the area, and periodically during the course of the working to confirm that changes have not occurred.

A possible method of oxygen detection could be odorisation. The odorisation is occasionally used in shipyards, because there is a certain risk of oxygen enrichment while welding in small ship rooms. (For details see Ref.2). However, odorisation must only be viewed as a possible supplement to effective risk analysis, isolation, and atmospheric monitoring, and not as an alternative to them.

7.1 Measuring Instruments

Oxygen measuring instruments should be used as warning devices only, and should not be regarded as protection against the risks of oxygen enrichment. They should be seen as an addition to normal good practice of eliminating the causes of enrichment. Measuring instruments for the determination of the oxygen content indicate an increase as well as a decrease of the oxygen concentration in the ambient atmosphere and have, for example, a range from 0 to 40 % by volume of oxygen.

Various measuring techniques and methods are used giving visible and/or audible warning and they can be used for continuous or intermittent measurement.

7.2 Choice of the measuring method

When working in a room where the oxygen content can vary outside of 19.5 to 22.5%, continuous oxygen monitoring shall be used. When an abnormal condition is detected by the monitor, a flashing light visual alert in a colour locally recognised to represent danger and a horn audible alert shall be activated. The light and horn should be located so that they may be detected by personnel in the monitored area as well as at the points of ingress to the room. Signs should be posted at all points of ingress warning of the potential hazard.

7.3 Accuracy

The uncertainty of the measuring method should be such that when indicating 21 % the real value is between 19.5 % and 22.5 % oxygen in the air.

Instruments shall be calibrated before use and at regular intervals during use.

7.4 Utilisation of measuring instruments

The directions of the manufacturers for the use and maintenance of the measuring instruments shall be carefully observed.

The measuring instrument shall be located in the working area and as near as possible to the worker. In confined spaces, it is recommended that the worker is equipped with a personal monitor attached to his/her working clothes which will give an audible and/or visual alarm if the oxygen content of the atmosphere deviates from that of normal air. In areas with high noise levels, visual alarms are recommended.

8 Protection of personnel

8.1 Clothes

Many so-called "non-flammable" textile materials will burn fiercely in oxygen-enriched air.

Some synthetic materials can be fire-resistant to some extent, but can still melt and cause serious burns due to the adhesion of molten material to the skin. Synthetic materials are not recommended.

Using Flame retardant clothing can be useful, but washing can reduce the effectiveness of the treatment.

Whatever one wears, it is impossible to avoid danger from an oxygen fire solely by protective clothing. .

Clothing should be well fitting, yet easy to remove and free from oil and grease.

Persons who have been exposed to an oxygen-enriched atmosphere may not smoke or go near naked flames, hot spots or sparks until they have properly ventilated their clothes in a normal atmosphere. A ventilation period of 15 minutes minimum with movement of the arms and legs and with coats unbuttoned is recommended.

8.2 Analysis

Before persons enter a space which can be subject to oxygen enrichment, the atmosphere shall be analysed for oxygen by a reliable, accurate analyser (see section 7). Entrance is permissible only if the oxygen concentration is equal to that of normal air. All other concentrations, that is 23 % or more, are potentially dangerous. However, as a warning against local or temporary variation in concentration, it is recommended that anyone entering such a space should be issued with a personal continuous automatic oxygen analyser which sounds an audible alarm when the oxygen concentration in the atmosphere varies above 22.5% or below 19.5%.

8.3 Fire fighting equipment

The only effective way of dealing with oxygen-feed fires is to isolate the supply of oxygen. Under oxygen rich conditions, fire-fighting media could be water, dry chemical (powder) or carbon dioxide. The choice between these media needs to take into account the nature of the fire, e.g. electrical, etc. Burning clothing for example shall be extinguished by a large amount of water to remove as much heat to the skin as possible.

Fire fighting equipment should be properly maintained and operating personnel should know where it is located, how to operate it, and which equipment to use for which type of fire.

8.4 Smoking

All personnel shall be informed of the dangers of smoking when working with oxygen or in an area where oxygen enrichment can occur. Many burning accidents have been initiated by the lighting of a cigarette; it is therefore imperative to emphasise the danger of smoking in oxygen-enriched atmospheres or where oxygen enrichment can occur. In such areas smoking shall be forbidden.

8.5 First Aid

A person catching fire in an enriched oxygen atmosphere cannot be rescued by a person entering the area to pull them out, as the rescuer will almost certainly also catch fire. The victim shall be deluged with water from a shower, hose or series of fire buckets and go into fresh air as soon as possible.

9 Summary of recommendations

The more important points, which have to receive attention if accidents are to be avoided, are summarised below.

a) Ensure that people who are expected to work with oxygen, are properly trained and informed of the risks caused by an excess of oxygen.
b) Make sure that the proper equipment is used and that it is leak-tight and in good operational order.
c) Use only materials and equipment approved for use in oxygen. Never use replacement parts which have not been specifically approved.
d) Use suitable clean clothing, free from oil and easily combustible contaminants.
e) Never use oil or grease to lubricate oxygen equipment.
f) Check that all existing fire extinguishing equipment is in good condition and ready to be used.
g) When working in confined spaces where oxygen is normally used, isolate the equipment, provide good ventilation and use an oxygen analyser. Entry shall only be allowed by means of a permit issued by a trained responsible person
h) Smoking shall be strictly forbidden where there is any possible risk of oxygen enrichment.
i) A person catching fire in enriched oxygen atmospheres cannot be rescued by a person entering the area to pull them out, as the rescuer will almost certainly also catch fire.
j) People who have been exposed to oxygen enriched atmospheres shall not be allowed to approach open flames, burning cigarettes, etc., until after adequate ventilation of their clothing.
k) Make sure that all oxygen apparatus and equipment is properly identified.

Escape routes must be kept clear at all times.

APPENDIX A

References

[1]. Cleaning of equipment for oxygen service
EIGA: IGC Doc 33/97 (adopted as AIGA 012/04)

[2]. Odorisation of oxygen in combustion applications
EIGA: 911/03

[3]. Accident prevention in oxygen-rich and oxygen-deficient atmospheres
CGA Doc. P-14, 1992

[4]. The safe application of oxygen enriched atmospheres when packaging food
BCGA Doc. GN 5, 1998

[5]. The probability of fatality in oxygen enriched atmospheres due to spillage of liquid oxygen
BCGA Doc TR2, 1999

[6]. Reciprocating compressors for oxygen service
EIGA: IGC Doc. 10/81

[7]. Centrifugal compressors for oxygen service
EIGA: IGC Doc. 27/93

[8]. A method for estimating the offsite risks from bulk storage of liquefied oxygen
BCGA Report R 1, 1984

APPENDIX B

Properties of oxygen
Oxygen supports combustion

- Oxygen is essential to life, the normal concentration in the air we breathe is approximately 21 %. It is not flammable but supports combustion. Most materials burn fiercely sometimes explosively in oxygen. As the oxygen concentration in air increases, the potential fire risk increases. At concentrations above 23 % in air, the situation becomes dangerous due to the increased fire hazard.

AIGA

APPENDIX B

Properties of oxygen
Oxygen gives no warning

- Because oxygen is colourless, odourless and tasteless, oxygen enrichment cannot be detected by the normal human senses.

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APPENDIX B

Properties of oxygen
Oxygen is heavier than air

- Being heavier than air, oxygen can accumulate in low lying areas such as pits or underground rooms, especially in cases of liquid spillage

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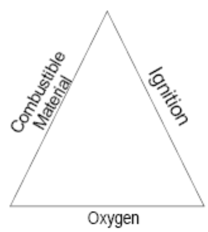
APPENDIX B

Necessary conditions for a fire

In general for a fire or explosion to occur, three elements are required:

combustible material, oxygen and an ignition source

The Fire Triangle is the normal way of representing these conditions



When one of the 3 elements is missing a fire cannot occur.

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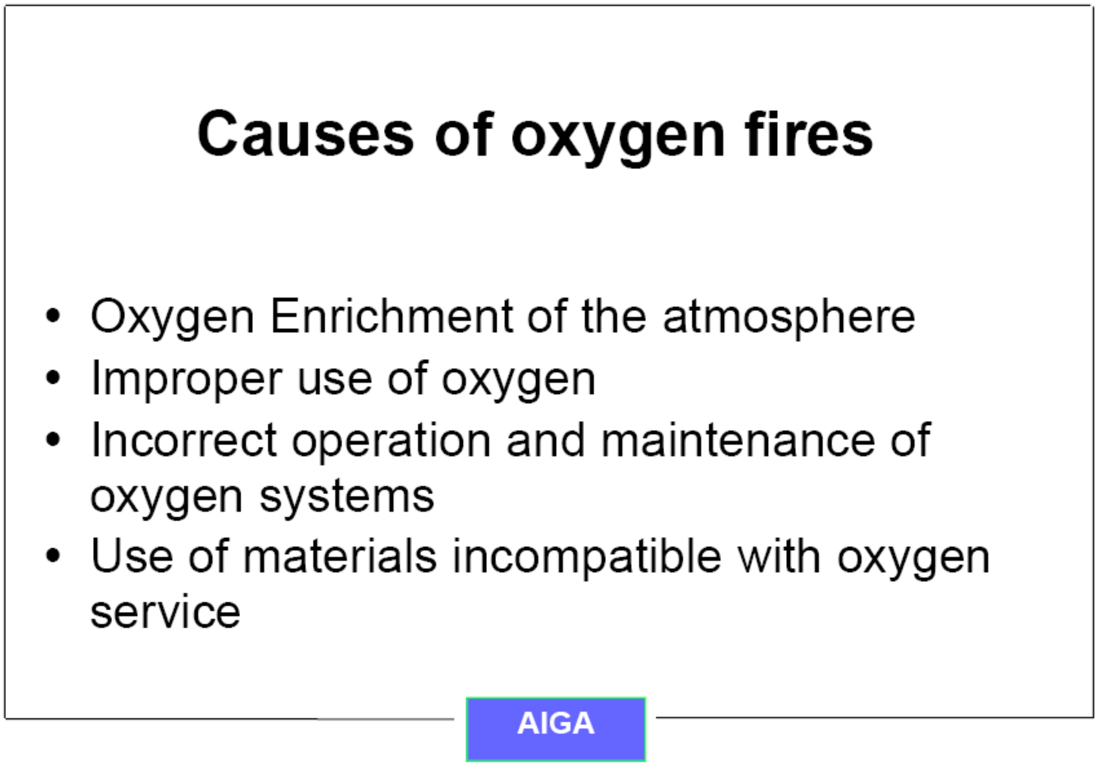
APPENDIX B


Causes of oxygen fires
• Oxygen Enrichment of the atmosphere
• Improper use of oxygen
• Incorrect operation and maintenance of oxygen systems
• Use of materials incompatible with oxygen service
AIGA

APPENDIX B

Compatibility of materials

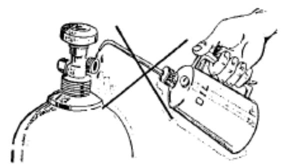
- Only certain materials are suitable for use in oxygen service.
- Most materials will burn in pure oxygen, even if they cannot be ignited in air.
- Oils, grease and materials contaminated with these substances are particularly hazardous in the presence of oxygen, as they can ignite extremely easily and burn with explosive violence.

AIGA

APPENDIX B

Never use oil or grease to lubricate oxygen equipment!

- Equipment contaminated with oil and grease shall be cleaned using approved cleaning agents/methods.



Check with your supervisor that any material/part or substance you intend to use is approved for oxygen service.

AIGA

APPENDIX B

Leaking equipment is very dangerous

- It could lead to oxygen enrichment, i. e. increased fire hazard.
  Leaking connections, flanges, fittings are hazardous causing the oxygen concentration to increase especially where there is not sufficient ventilation. All equipment, newly assembled or after maintenance, has to be thoroughly leak tested before going into service.

AIGA

APPENDIX B

Liquid Oxygen spill

- A spill of liquid oxygen creates a dense cloud of oxygen enriched air as it evaporates.
- The clothing of personnel entering the cloud will become enriched with oxygen.
- When liquid oxygen impregnates the soil which contains organic material, e.g. wood, asphalt, etc., a dangerous situation exists, as the organic material is liable to explode when impacted.

AIGA

APPENDIX B

Do not use oxygen for applications for which it is not intended!

Do not use oxygen as a substitute for air, e. g. for:

- operating pneumatic tools
- inflating tyres
- starting diesel engines
- dusting benches, machinery or clothing

AIGA

APPENDIX B

In areas where oxygen enrichment can occur, do not smoke and do not use naked flames

If hot work (welding, flame cutting, soldering, grinding, etc.) has to be carried out, ensure that the atmosphere has been checked and confirmed as safe and obtain a Permit to Work.

AIGA

If you have been in an oxygen enriched atmosphere ventilate your clothing in the open air for at least 15 minutes before smoking or going near a source of ignition.

AIGA

APPENDIX C

Examples of oxygen enrichment accidents.

Had the recommendations of this Document been followed none of the following would have occurred

1. A safety valve on a gaseous oxygen supply line was greased during repair. When the safety valve was later checked under oxygen pressure, the **grease** ignited and the operator was badly injured.

2. A worker wanted to check the pressure of oxygen cylinders. He used a pressure gauge filled with **glycerine**, not suitable for oxygen service. When opening the valve the pressure gauge exploded, resulting in nearly total blindness of the worker.

3. A fitter lost the Teflon gasket of his oxygen regulator. Arriving at the place where he had to do a repair, he made a **rubber gasket** from an inner car tire and connected the regulator to the cylinder valve outlet.
   When he opened the cylinder, due to the use of a non-oxygen compatible gasket, a flash occurred burning his upper arm and shoulder.

4. A worker was welding on the outside of an oxygen pipeline. Before starting the work the welder isolated the pipeline by closing the valve, purging the pipeline and checking the atmosphere. Suddenly the welder was engulfed in flames and subsequently died of his burns. The valve was later found to be **leaking** allowing oxygen to enter the isolated pipeline.

5. At a factory, a valve on an **oxygen feed line** which ran into the plant shop **was left open**. A man's clothing ignited when contacted by electric welding sparks. He ran out and rolled on the grass but was seriously burnt. Several others who assisted were slightly burnt.

6. A worker attempted to change a blowpipe by nipping the oxygen hose. **Escaping oxygen** caused fire resulting in serious burns to the worker.

7. Men were working on the roof of an oxygen factory near a main **oxygen vent** which was operating. One man began to smoke, his clothing ignited and he was burned to death.

8. A contractor employee had to grind away a piece of railing on a platform at the air separation column.
   A Work Permit had been issued and a pre-job discussion had been held. The ambient temperatures were low and while waiting for a colleague he leaned over and partially sat down on an oxygen vent warming himself on the escaping relatively warm oxygen leaking through the valve. The moment he started grinding, a spark set his **oxygen saturated clothing** alight, causing burns on his total body of 2nd and 3rd degree resulting in months of hospital treatment.

9. When using an oxygen lance in a steel foundry, an operator realised that the coupling between hose and lance was leaking, but did not mind because it provided some cooling on his stomach. A spark of hot metal was projected towards the operator and ignited the **oxygen saturated clothing** at his stomach, resulting in serious burns.

10. An air powered rotary drill was connected by means of an adapter to an oxygen line. After several hours, the air in the working compartment had become so **enriched with oxygen** that when one of the workers lit a cigarette it flared up, ignited clothing, resulting in four fatalities and five other men being injured

11. A welder was working in a tank car. After a while, he interrupted his work in order to renew the air in the tank by **introducing oxygen**. When he resumed his welding a spark ignited his clothing. The worker succumbed to fatal burns.

12. A steelworker attempted to repair his car which had a blockage in the fuel line. He **used oxygen to clear the blockage** and the fuel tank exploded killing one person.

13. There are several reports of men being set on fire due to walking into the gas cloud from an **oxygen spillage** while smoking.

14. A person who was wearing proper clothing was working in an **oxygen enriched atmosphere**. He went to a smoking area and immediately lit a cigarette, whereupon his clothing ignited.

APPENDIX C

15. Several incidents are reported of hospital patients who had their clothing and bedding set on fire due to **smoking or sparks while receiving oxygen treatment**.

16. Several instances have been reported of deaths in hyperbaric chambers due to **smoking or electrostatic sparking under enriched oxygen conditions.** In one case 10 people were killed when a fire broke out caused by a portable hand warmer being used.

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APPENDIX B

The transport of live fish A review

EIFAC
TECHNICAL
PAPER

48

by
R. Berka
Fisheries Research Institute
Scientific Information Centre
389 25 Vodňany
Czechoslovakia

EUROPEAN INLAND FISHERIES
ADVISORY COMMISSION
(EIFAC)

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PREPARATION OF THIS DOCUMENT

The present document is based on a general review of the existing literature concerned with live fish transport. It has been prepared by the author in 1983–84 as a voluntary contribution, for which EIFAC is most grateful.

The cover photo graph is by A.G. Coche. It represents the transport of carp fry in plastic bags with addition of oxygen.

ABSTRACT

The basic principles of fish transport and the main factors affecting it (fish species, fish developmental stages and quality, transport time, temperature, oxygen content, fish metabolism products, etc.) are evaluated on the basis of an analysis of the pertinent literature. For the two basic fish transport systems, the closed and the open ones, the transport units are described and the densities of transported fish per unit volume under actual conditions are tabulated for guidance. The survey is complemented by the description of the existing methods for the chemical treatment of the environment inside the transport systems and for the treatment of the fish transported, such as fish anaesthetics, chemical water conditioning and antibacterial treatment.

Distribution:

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CONTENTS

1. INTRODUCTION

There are two basic transport systems for live fish - the closed system and the open system. The closed system is a sealed container in which all the requirements for survival are self-contained. The simplest of these is a sealed plastic bag partly filled with water and oxygen. The open system consists of water-filled containers in which the requirements for survival are supplied continuously from outside sources. The simplest of these is a small tank with an aerator stone.

These systems will be reviewed with respect to the problems of fish preparation for transport, types of vehicles and equipments, problems of water quality and its changes during transport, and chemical aids used during fish transport.

There is ample literature on fish transport and associated problems; however, the literary sources overlap and give partly differing interpretations of the recommended ways of transport. These are the reasons why this survey aims at comprising mainly those published results which have been fully verified in practice and which are, therefore, reliably instructive.

The basic factors and principles associated with any live fish transport systems, or influencing them, are evaluated before the actual ways of fish transport are commented on.

2. THE MAIN FACTORS AND PRINCIPLES ASSOCIATED WITH FISH TRANSPORT

Fish survival in a good state of health during transport is influenced by a number of factors, or combination of factors.

2.1 Quality of Fish

The quality of fish transported is a decisive criterion. The fish to be transported must be healthy and in good condition. Weakened individuals should be eliminated from the consignment, particularly when the temperature during shipment is high. When the fish are of poor quality, even a great reduction of fish density in the transport container fails to prevent fish losses. Weak fish are killed at a much higher rate than fish in good condition when the transport time is longer.

A need for adapting the fish to a lower water temperature may also arise before transport. Natural ice is used to cool the water; the ice of carbonic acid should be avoided. As a guide ratio, 25 kg of ice will cool 1 000 litres of water by 2°C. If the water contains fish during the cooling process, the temperature drop should not be faster than 5°C per hour. Direct contact of fish with ice should be prevented at the same time. The total temperature difference should not be greater than 12–15°C, with respect to the species and age of the fish (FRG recommendation, 1979).

The fish to be transported, except for the larval stages should be left to starve for at least a day; if the digestive tract of the fish is not totally cleaned, the possible time of transport is reduced to a half, though the conditions may be the same (Pecha, Berka and Kouril, 1983; Orlov *et al.*, 1974). The fish with full digestive tracts also need more oxygen, are more susceptible to stress, and produce excrements which take up much of the oxygen of the water. However, when fish larvae are transported, their time of survival without food should be taken into consideration. The transport time of the larvae of herbivorous fishes should not last longer than 20 hours and that of many aquarium species should be shorter than 12 hours (Orlov, 1971).

2.2 Oxygen

The most important single factor in transporting fish is providing an adequate level of dissolved oxygen. However, an abundance of oxygen within a tank does not necessarily indicate that the fish are in good condition. The ability of fish to use oxygen depends on their tolerance to stress, water temperature, pH, and concentrations of carbon dioxide and metabolic products such as ammonia.

The crucial factors underlying oxygen consumption by fish in relation with oxygen metabolism during transport are fish weight and water temperature. Heavier fish and those transported in warmer water need more oxygen. For instance, if the water temperature increases by 10°C (e.g., from 10 to 20°C), oxygen consumption is about doubled. From the point of view of fish transport, for each 0.5°C rise in temperature, the fish load should be reduced by about 5.6%; conversely, for each 0.5°C decrease in temperature, the load can be increased by about 5.6% (Piper *et al.*, 1982). Oxygen consumption also increases with fish excitement by handling. Excitement increases oxygen demand three to five times and, for instance, salmonid fry need up to several hours to return to the normal level of oxygen metabolism which is, in fact, usually after the end of the transport (Lusk and Krcál, 1974).

In water provided with an unlimited amount of oxygen, a fish at rest will consume a minimum amount of oxygen. In a fish transport system, the fish will require more than the minimum amount since they are not at rest. Furthermore, if they are excited at loading or disturbed during transport they may consume near to the maximum amount.

The amount of oxygen a fish consumes also depends on the amount of oxygen available. At high levels, the fish will consume at a steady rate. When water oxygen levels are low, fish consume lower amounts of oxygen than when oxygen levels are high, despite the degree of activity.

Fish transport systems often contain water with oxygen levels that do not provide enough oxygen required to satisfy the fish bodies. To offset this predicament, the fish will shift its metabolism to use the stored oxygen of the body. This condition is likened to that of a man who is at rest and suddenly performs strenuous activity before a proportionate amount of oxygen is taken in. For the man and the fish, an oxygen "debt" is created which must be repaid when favourable oxygen conditions are experienced.

The first hour after loading is a particularly critical time for fish in respect to their oxygen needs. They are excited and require a large amount of oxygen with a short time for adjustment. Significant differences in oxygen demand exist also within fish families. As asserted, for instance, by Uryn (1971), when water temperature increases (4–14°C) during transport, the fry of *Coregonus lavaretus* consume 2.4 times more oxygen than the fry of *C. albula*. Fish size is also important. A large fish consumes less oxygen per unit weight than does a small one. Oxygen levels of water for most warm water fish should be above 5 $mg.1^{-1}$ for normal conditions. This level should prevent oxygen from becoming a major stress factor.

Some conversion coefficients of oxygen demand are indicated by the FRG recommendation (1979): 25 kg of rainbow trout at an individual weight of 250 g have the same oxygen demand as 20 kg of 12 cm stock trout (1 100 fish), or 17 kg of 8 cm stock trout (3 200 fish), or 12 kg of forced fry at the length of 4 cm (ca. 23 000 fish). Taking the oxygen demand of carp as 1, the converted oxygen demand levels for other fishes are as follows:

trout	2.83	bream	1.41
pike-perch	1.76	pike	1.10
roach	1.51	eel	0.83
perch	1.46	tench	0.83

According to Shevchenko (1978), the oxygen consumption of *Coregonus peled* per kg of weight per hour at a temperature of 10°C is 100 mg; in sturgeon this value is 68 mg, in pike 50–60 mg, and in carp weighing 500–600 g it is 45 mg.

During fish transport in closed systems with pressurized oxygen atmosphere, oxygen content in water usually is not a limiting factor because there is enough pressurized oxygen in a closed bag. Oxygen deficit may occur in exceptional cases when the density of fish is too high or the transport is longer than the fish can stand. The dead fish compete with the living ones for oxygen: they increase bacterial multiplication requiring much oxygen, and this multiplication may further produce toxic metabolites. The slime produced by the fish is another substrate for bacterial growth resulting in a decrease of the water oxygen content; this process is intensified when water temperature is higher.

A high oxygen content of water has no unfavourable influence on the fish, e.g., the limit for rainbow trout is 35 mg per litre which is not attainable in practical conditions, as asserted by Heiner (1983); the fish are able to regulate the volume of oxygen entering their bodies. This holds generally with possible exceptions; for the time being there are no data on the effect of a longer exposure to a high oxygen content at a higher temperature in the larval stages of fish unable to keep oxygen content of their blood at an optimum level.

In closed systems, slight shaking of the bag supports the penetration of atmospheric oxygen to water. During long steps when the bags with fish are left without movement, the fish may die though the oxygen reserve in the bag is still high. This applies mainly to dense stocks of salmonids, requiring much oxygen; no such problems are encountered when cyprinids, except their sac fry, are transported, because these fish move the water in the bag by their own movement, thus driving it into sufficient contact with the oxygenated atmosphere. The time of the onset of the threshold oxygen concentrations during salmonid fry transport in closed bags left without movement is suggested in Table 1 (Orlov *et al.*, 1974).

2.3 pH, Carbon Dioxide and Ammonia

Water quality is a function of the load of fish concentration and the length of time for which the fish are transported. The source of the water used during transport must have been tested before dispatching a mass consignment of fish. The water pH level is a control factor because the proportions of toxic ammonia and CO_2 contents are direct functions of pH (Fig. 1).

With increasing transport time, CO_2 production through fish respiration shifts water pH towards acidity. Water pH levels about 7–8 are considered as optimum. Rapid changes in pH stress fish, but buffers can be used to stabilize the water pH during fish transport. The organic buffer trishydroxylmethylaminomethane is quite effective in fresh and salt water. It is highly soluble, stable and easily applied. This buffer has been used on 29 species of fish with no deleterious effects. Levels of 1.3–2.6 g/litre are recommended for routine transport of fish (Piper *et al.*, 1982).

Table 1

The onset of the threshold concentrations of oxygen during salmonid fry transport in closed bags without movement
(in hours)

Individual average weight (g)	Temperature (°C)	Total weight of fish (kg)						
		0.25	0.5	1.0	1.5	2.0	2.5	3.0
0.5	5	10.0	-	-	-	-	-	-
	10	10.0	-	-	-	-	-	-
	15	6.0	-	-	-	-	-	-
	20	3.9	-	-	-	-	-	-
1–2	5	10.0	10.0	-	-	-	-	-
	10	10.0	6.0	-	-	-	-	-
	15	6.7	3.3	-	-	-	-	-
	20	4.4	2.2	-	-	-	-	-
5–10	5	10.0	10.0	7.3	4.7	-	-	-
	10	10.0	6.6	3.2	2.1	-	-	-
	15	8.0	3.9	1.9	1.2	-	-	-
	20	5.3	2.6	1.3	0.8	-	-	-
20–50	5	10.0	10.0	9.1	5.9	4.3	-	-
	10	10.0	7.3	3.5	2.3	1.7	-	-
	15	9.2	4.5	2.2	1.4	1.0	-	-
	20	5.8	2.8	1.4	0.9	0.7	-	-
100	5	10.0	10.0	10.0	6.7	4.9	3.8	3.1
	10	10.0	8.2	4.0	2.6	1.9	1.5	1.2
	15	10.0	4.9	2.4	1.5	1.1	0.9	0.7
	20	6.5	3.2	1.5	1.0	0.7	0.6	0.5

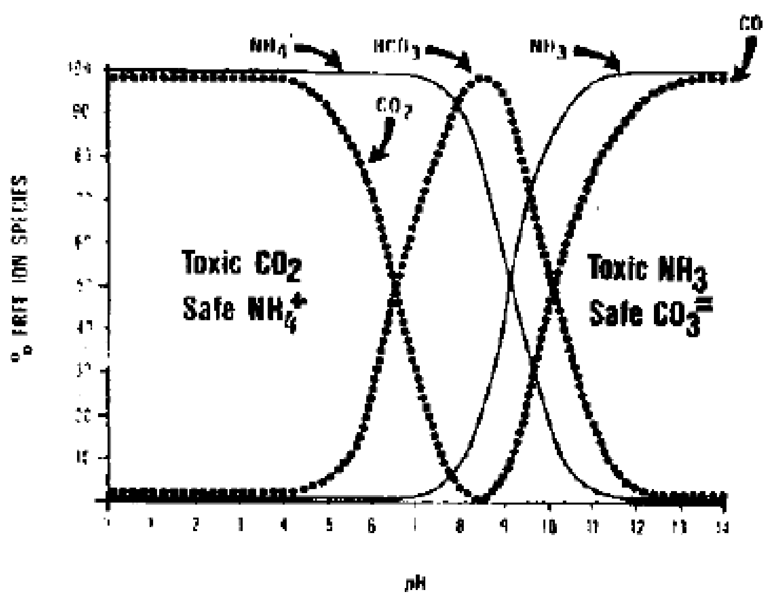


Figure 1 Proportion of each chemical species of ammonia and carbon dioxide expressed as a percentage at various pH levels (Amend *et al.*, 1982)

Elevated carbon dioxide concentrations are detrimental to fish and can be a limiting factor in fish transport. A product of fish and bacterial respiration, CO_2 acidifies transport water. Although this reduces the percentage of un-ionized ammonia in the water, it also reduces the oxygen-carrying capacity of fish blood. Fish may succumb if CO_2 levels are high, even though oxygen levels are seemingly adequate. Trout appear to tolerate carbon dioxide at levels less than 15 mg 1^{-1} in the presence of reasonable oxygen and temperature, but become distressed when carbon dioxide levels approach 25 mg 1^{-1} (Piper *et al.*, 1982).

Fish transported in tanks are exposed to gradually increasing concentrations of carbon dioxide. Unless aeration is adequate, CO_2 levels may exceed 20–30 mg 1^{-1}, in general, for each milliliter of oxygen a fish consumes, it produces approximately 0.9 milliliters of CO_2. If the CO_2 level increases rapidly, as with heavy fish loads, fish become distressed. However, elevated concentrations of CO_2 can be tolerated if the rate of buildup is slow.

Adequate ventilation is a necessity for transport units. Tight covers or lids on the units can result in a buildup of CO_2 which will stress the fish. Aeration of the water will reduce concentrations of dissolved CO_2, if there is adequate ventilation.

As Pecha, Berka and Kouril (1983) assert, the critical CO_2 concentrations in closed systems range about 140 ml/litre for thermophilous fish and about 40 ml/litre for those preferring cold conditions. Kruzhalina, Averina and Vol'nova (1970) give a closer specification of these critical CO_2 concentrations in closed fish transport systems and suggest the following levels: 60–70 ml/litre for salmonids, 40 ml/litre for mature sturgeons and 20 ml/litre for sturgeon fry, 140–160 ml/litre for mature herbivourous fishes, 100 ml/litre for herbivorous fish fry and 80 ml/litre for the larvae of the herbivourous species. All these data hold for closed systems; in open systems CO_2 is released from water by any system of aeration. When the fish concentration in the container of a closed system decreases, the critical CO_2 concentration loses much of its importance.

Another important factor is chlorine concentration in water, although - like carbon dioxide - chlorine is also removed from the water by aeration. The concentration of 0.5 mg/litre is considered as dangerous, though even lower chlorine levels, e.g., 0.2 mg/litre disturb the fish respiration mechanism considerably (Shevchenko, 1978).

Ammonia (NH_3) builds up in transport water due to protein metabolism of the fish and bacterial action on the waste. Decreasing metabolic rate of the fish by lowering the water temperature, and thus lessening fish activity, reduces the production of NH_3. The production of NH_3 by bacterial action can be decreased by shipping fish only after food has been witheld long enough to void the stomach and intestine.

Temperature and time of last feeding are important factors regulating ammonia excretion. For example, trout held in water at 1°C excrete 66% less ammonia than those held in 11°C water, and fish starved for 63 h before shipment produce half as much ammonia as recently fed fish. Fish larger than 10 cm should be starved at least 48 h; those 20 cm and larger should be starved 72 h (Piper *et al.*, 1982).

The amount of un-ionized ammonia increases as water temperatures and pH increase (Table 2).

No maximum permissible values can be given because the toxicity of ammonia is so greatly affected by water temperature and pH. However, critical concentrations of toxic ammonia are scarcely obtained under standard fish transport conditions.

2.4 Temperature

Water temperature is an important factor. When water temperature is low, the pH remains higher and fish metabolism decreases. The generally applicable zones of optimum temperatures for transported fish are 6–8°C for cold-water fishes and 10–12°C for warm-water fishes in summer, 3–5°C for cold-water fishes and 5–6°C for warm-water fishes in spring and autumn, and 1–2°C for all in winter. Naturally, these temperature ranges do not apply to the early stages of fish fry. The early fry of cyprinids cannot be transported at temperatures below 15°C, early fry of salmonids at temperatures higher than 15–20°C, and the temperature of 10°C, is considered as optimum for the early stages of the fry of coregonids (Pecha, Berka and Kouril, 1983; Orlov *et al.*, 1971, 1974; Shevchenko, 1978).

2.5 Density and Activity of Transported Fish

Consideration should also be given to the factor of space. As to fry, the ratio of the volume of the fish transported and the transport water should not exceed 1:3. Heavier individuals, e.g., parent fish can be transported in a fish: water weight ratio of 1:2 to 1:3, but with smaller organisms this ratio decreases to 1:100 to 1:200 (Pecha, Berka and Kouril, 1983). In the FRG recommendation (1979), the following ratios between fish weight and the volume of water in the transport tank (with good aeration of water at a temperature of 8–12°C during shorter transports lasting (1–2 h) are table carp 1:1, stock carp 1:1.5, table rainbow trout 1:3, stock trout 1:4.5, stock pike 1:2, herbivorous fishes 1:2.

Table 2

Percent un-ionized ammonia in water at 0 to 30°C and pH 6 to10 (Emerson *et al.*, 1975)

Temperature (°C)	pH				
	6.0	7.0	8.0	9.0	10.0
0	0.008	0.08	0.82	7.64	45.3
2	0.01	0.10	0.97	8.90	49.3
4	0.01	0.12	1.14	10.3	53.5
6	0.01	0.14	1.34	11.9	57.6
8	0.02	0.16	1.57	13.7	61.4
10	0.02	0.19	1.83	15.7	65.1
12	0.02	0.22	2.13	17.9	68.5
14	0.03	0.25	2.48	20.2	71.7
16	0.03	0.29	2.87	22.8	74.7
18	0.03	0.34	3.31	25.5	77.4
20	0.04	0.40	3.82	28.4	79.9
22	0.05	0.46	4.39	31.5	82.1
24	0.05	0.53	5.03	34.6	84.1
26	0.06	0.61	5.75	37.9	85.9
28	0.07	0.70	6.56	41.2	87.5
30	0.08	0.80	7.46	44.6	89.0

The conditions of fish transport are also influenced by overexertion and fatigue of fish. When fish are placed in transport containers, they usually exert a large amount of muscular activity. When muscles are actively used, there is not enough blood (thus oxygen) to supply their needs. An alternate system shifts into use where energy is provided in the absence of normal amounts of oxygen. Lactic acid accumulates in the muscles and blood and causes the pH of the blood to drop. Oxygen utilization is reduced by the lower pH of the blood. Following a few minutes of strenuous muscular activity, lactic acid accumulation may not be reduced for 24 h. Excitability and recovery from the side effects excitement vary with the species. More oxygen is consumed within the first 15 min. in the transport unit than during any subsequent 15-min period (Dupree and Huner, 1984). For this reason, additional oxygen, as much as twice the flow normally required should be provided during loading and the first hour of hauling. The oxygen flow can be reduced to normal level 6 mg 1^{-1} after this acclimation period, when the fish have become settled and oxygen consumption has stabilized (Piper *et al.*, 1982).

A lower individual weight of fish means a much lower total weight of the fish that can be kept in a transport container (Fig. 2); this is due to the higher oxygen consumption and greater demand for space (the space factor increases considerably).

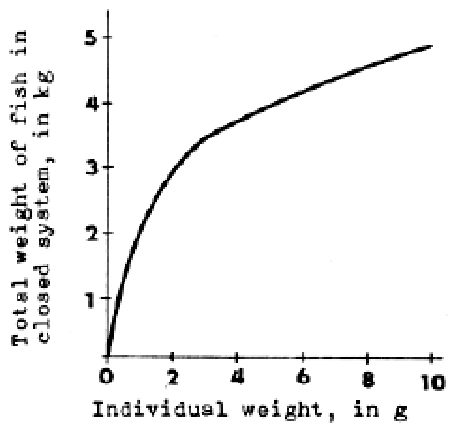


Figure 2 The dependence of cyprinid stock density in closed systems on the individual fish weight, in water temperature 20°C and transport time 5 h (Orlov *et al.*, 1974)

Stock density of the fish in container also depends on the length of transport time (Fig. 3). The pattern of this dependence is characterized by hyperbolic curve, not straight line.

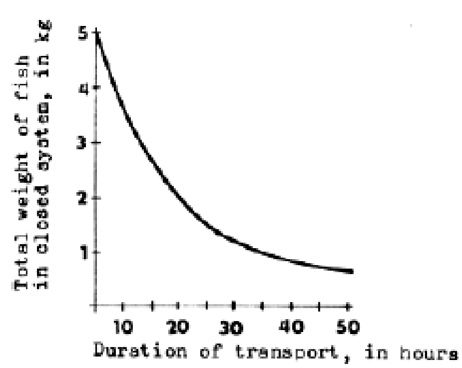


Figure 3 The dependence of the stock density of cyprinids in a closed system on shipment time; individual weight 10 g, transport time 5 h, water temperature 20°C (Orlov *et al.*, 1974)

The relation between the fish stock density in the container and water temperature is shown in Fig. 4. Higher temperatures mean a lower total stock weight.

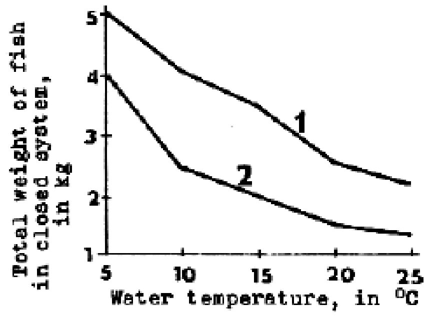


Figure 4 The dependence of cyprinid stock density in a closed system on water temperature; 1 - individual weight 10 g, transport time 15 h; 2 - individual weight 5 g, transport time 25 h (Orlov *et al.*, 1974)

The time of shipment experts its influence mainly on the larval stages of cyprinids; transport longer than 24 h always means some risk, although all conditions are otherwise good (Pecha, Berka and Kouril, 1983).

Salmonid stock densities in the transport container are always lower than the standard densities for cyprinids, owing to a higher oxygen consumption and a lower critical CO_2 concentration.

2.6 Biochemical Changes and Stress in Transported Fish

Shipment conditions also influence the composition of fish blood and the parameters of blood serum biochemistry. Increased temperature and a lower fish weight-to-water concentration ratio mean a higher number of erythrocytes and a greater haemoglobin concentration of fish blood. No such changes occur at lower temperatures and a lower fish proportion in relation to water volume (Shevchenko, 1978). Haematological conditions changed by transport were also recorded by Carmichael (1984) in advanced fingerlings (15–24 cm) of largemouth bass. When fish were transported at higher densities, the levels of corticoids and glucose in the plasma increased and were retained when the transport was finished. Although mortality as a direct consequence of transport was low, the secondary effects of stress were responsible for delayed mortality, caused by the consequences of osmoregulatory disfunction and disease. For largemouth bass, the author recommends to let the fish recover for at least 64 h.

It should also be noted that release of fish at the destination can be the most critical stage of the transport process. The fish are under some degree of stress in the transport unit and sudden exposure to water of different characteristies or low quality will further stress the fish, often beyond what they can stand. Poor-quality water may mean freshly pumped ground water with low oxygen or high carbon dioxide content. Different characteristics of water often mean a pH, temperature or gas saturation difference between the transport unit and the receiving water.

2.7 General Notes

Finally, several concluding notes, or technical and organizational considerations, can be quoted from the literature. The majority of authors recommend, irrespective of the guide numbers of stock density during transport, to consider the specific transport conditions in each case and to change the basic guide numbers if such a change appears necessary after a brief test. It is also recommended to use a fish density at which the time of transport can be prolonged at least 1.5 times to prevent the consequences of a possible delay during transport, e.g., failure of a truck, failure to stick to the train or plane schedule, etc. When fish are transported for acclimation, or when endangered species are transported, the stock density should be lower: in such cases the economic aspects are not of primary importance and 100% survival is required. Nevertheless, the economic side of transport can never be neglected; hence, when the transport costs are high and the value of fish of transported comparatively low, the stock density in the transport units can be increased though losses of fish may be expected to be higher.

3. CLOSED SYSTEMS OF FISH TRANSPORT

The closed systems are represented by polyethylene bags and other sealed transport units. They are used mainly for the transport of the early fry, but also brood fish. The transport of fry in polyethylene bags with oxygen is particularly widespread in the world, being used as a very effective method. It substantially reduces the total volume and weight of transport water, enables public transport to be used for fish-transport purposes, makes it possible to prolong the transport time, and is economically advantageous.

The methods of fish transport in sealed medium are described in detail in several general studies (Orlov *et al.*, 1974; Kozlov *et al.*, 1977; Pecha, Berka and Kouril, 1983; Vollmann-Schipper, 1975; Woynarowich and Horváth, 1980) and in a number of separate specific studies (Bogdan, 1972; Hamman, 1981; Lusk and Krcál, 1974; Snow, Brewer and Wright, 1978; Garádi and Tarnai, 1983; Varga, 1984; Ioshev, 1980; Amend *et al.*, 1982; Popov, 1975; Kruzhalina, Averina and Vol'nova, 1970, 1984; Orlov, 1971, 1973, 1975; Orlov *et al.*, 1973, 1974). Soviet authors prevail because this method of stocking fish transport from hatcheries is used particularly frequently in the USSR.

3.1 Polyethylene Bags

The bags used for fish transport in water with oxygen atmosphere are produced in a number of modifications. They are manufactured from a thin (soft) or thicker (hard) transparent polyethylene foil and usually have the shape of sack or sleeve.

The bags of the traditional shape (sacs) usually have the dimensions of 0.8–1.1 × 0.35–0.45 m. The upper end is usually fully open. The bottom either has a seam in the middle or consists of a rectangular piece of foil; the latter variant is better because it helps avoid losses of the fish squeezed in the corners. For safety reasons, the bags are sometimes duplicated: a thin (soft) bag is inserted in another thin bag, or a thin bag forms a lining in a thicker (harder) bag.

The other type of bags has the form of a sleeve. Its width usually is 0.4–0.5 m. The final length of the sleeve depends on where the sleeve is cut. One of the ends has to be completely closed, sealed: a suture is welded, or the folded end of the sleeve is fused in, after tightening with a rubber seal or a plastic adhesive tape, or binding with a rope. The welding is done with a special device, whereas for the fusing (sealing) the flame of a candle will suffice (Fig. 5). Another possibility is to bind a knot on the end of the sleeve. It is important to make the knot as tight as possible. One sleeve equalling about 2.5 times the length of the future bag suffices, after binding a simple knot, to make a duplicated bag.

During transport the bags with fry are placed in outer cases protecting the bags against mechanical damage, mainly punching or tearing in contact with the ground. The case keeps the bags in the desired position, enables easier handling and/or provides thermal insulation of the bags.

These cases can be cardboard boxes, suitable plastic containers, wide polyethylene cans, polystyrene boxes. The kind of outer casing depends on the number of bags transported, length and method of transport, requirements for further handling (transloading), and on the differences between ambient temperature and the temperature of water inside the bag.

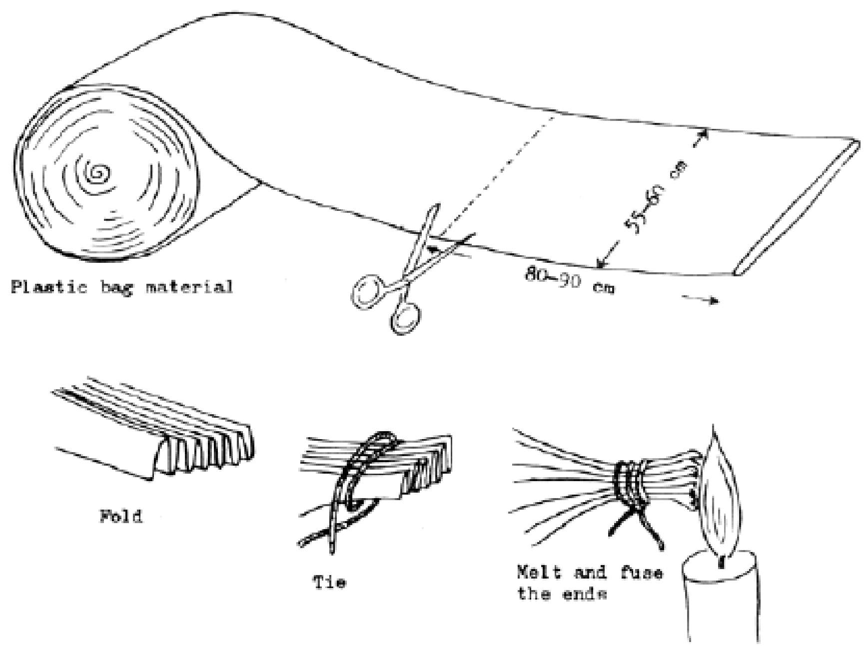


Figure 5 Procedure of closing the bottom end of a polyethylene sleeve (Woynarowich and Horváth, 1980)

If water with transported fry is to be cooled, bags with ice should be placed under the fish-transport bags on the bottom of the polystyrene box (Fig. 6). It is not recommended to put the ice inside the transport bag. The amount of ice depends on the size of the bag with water, transport time and difference of temperature. The volume of ice placed under the bag with transport water is usually 10–20% of the transport water. This method of packing enables transport by public transport routes.

The water to be used for fry transport in a bag should comply with all requirements. It is best to use water of the same quality as that in which the fish were kept before transport, but there should be no organic pollutants and no dispersed mud of mineral origin. Sac fry, in particular, need transport water with air bubbles, i.e., released air contained in water in oversaturated condition.

Before putting the fry in the bag, the procedure of catching, counting and distributing the fry in the bags should have been thoroughly prepared to finish the operation as quickly as possible.

The polyethylene sac, or sleeve with a closed bottom end, is first put in the outer transport case; if a double bag is to be used the inner bag is to have been inserted in the outer one. Then, water is poured in the bag, about 20 litres if the volume of the bag is 50 litres, and the fry are placed inside. Air is displaced from the space above water in the bag and a hose, connected to the pressure regulator of an oxygen cylinder, is introduced in the bag, the upper end of the bag being held tight around the hose by hand. Then, technical oxygen from the pressure cylinder is left to blow via the pressure regulator to the upper part of the bag. If the volume of water with fry is 20 litres, the volume of oxygen atmosphere should be 30 litres. The supply of oxygen is stopped when the bag is filled: the hose is quickly drawn out of the bag and the upper end of the bag is twisted to prevent oxygen from leaking and to produce some overpressure by reducing the volume. If the bag if to be transported in a horizontal position, the pressure should be 0.05 to 0.06 MPa but for vertical transport the pressure should be 0.02 to 0.04 MPs (Pecha, Berka and Kouril, 1983; Orlov *et al.*, 1973). In practice, this means that after filling the bag is tight: when pressed with thumb the foil quickly returns to its original position. During air transport the pressure in a vertically kept bag reaches -0.01 MPa (Orlov *et al.*, 1973), owing to the lower outside pressure. Finally the opening of the bag is closed. There are several ways of closing the bag; the simplest way is to tighten the end of the plastic foil with rubber, preferably duplicated. Rope or adhesive tape can also be used. The bag can also be closed with a metal screw cap. The procedure of bag filling is described in Fig. 7.

In hatcheries or fry rearing farms with regularly repeating mass dispatching of the fish, it is recommended to build a dispatching line (Fig. 8).

After transport, or during control on a longer journey, the condition of the fry should be checked before release. The fry are examined for position, i.e., swimming, lying on the bottom, staying in physiological position or turning to one side, for motility, readiness of reaction to light, touch, and/or number (proportion) of dead individuals.

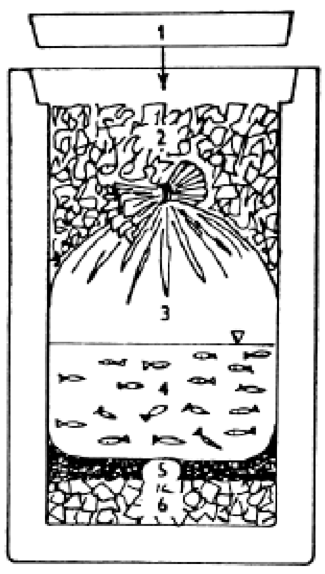


Figure 6 Transport of a bag in styrofoam case (Vollmann-Schipper, 1975)
1 - lid, 2 - insulation filling, 3 - oxygen atmosphere, 4 - water with fish, 5 - insulation lining, e.g., foam rubber, 6 - ice

The fish are released only when the temperature of the water in the bag reaches the same level as that of the receiving water. For sac fry the difference in water temperature should not be greater than 1°C, for older fry 2°C in both directions. To balance the temperatures it is best to put the closed bag on the surface of the receiving water. When the temperature difference is reduced to 2–3°C at the maximum, the bags are opened step by step and the receiving water is slowly added to the transport water. Releasing can start when about 50% of the receiving water has been added to the bags. The behaviour of the fry should be constantly examined (Fig. 9).

If the bags are handled with maximum care, if they are closed in the most careful manner and transported in suitable outer cases, they can be used repeatedly. However, this is not a general recommendation because damage to the bags, however tiny it may seem, can never be avoided during fish release.

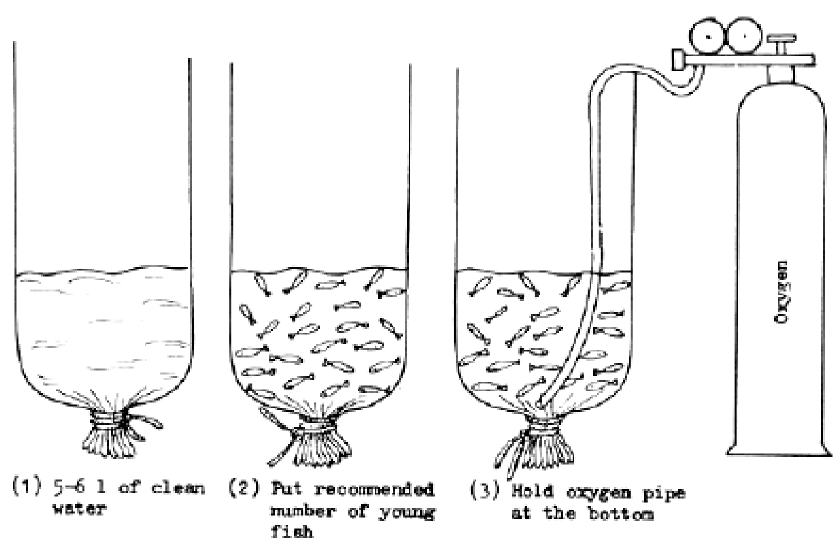
As Kruzhalina, Averina and Vol'nova (1970) assert, it is also possible to use bags - tanks, made of 4–12 layers of polyethylene foil ("sleeve" 80 cm in width), having a total volume of 300 litres. However, these types of bags are hard to handle and are used only for individual transports of large and broad fish.

3.2 Other Sealed Containers

Containers similar to polyethylene bags may be sealed. Generally made of cured plastics (Fig. 10) they can do the same job as bags and do not require as much care during handling, despite repeated use. However, their unit price is much higher.

3.3 Fry Densities in Plastic Bags

Calculation fromulae were worked out for the theoretical determination of fish densities in plastic bags (Orlov, 1971; Orlov *et al.*, 1974, 1975); they take into account factors such as changing environment, transport time, volume of water and coefficient of free space. Nevertheless, for practical purposes, it is simpler to use the guide data published by some authors, either individually or as fish-transport tables.



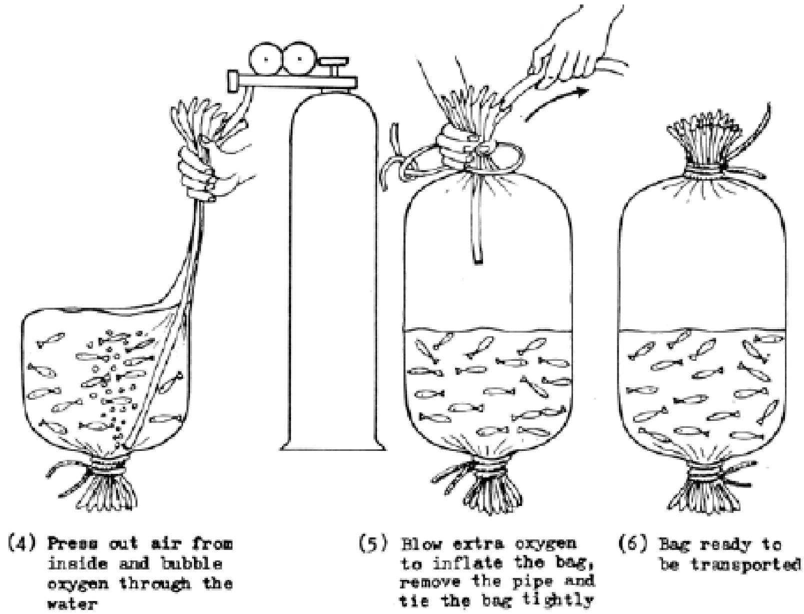


Figure 7 Procedure of filling the bag with water, stocking with the fish, displacing the air, introducing oxygen and closing the upper end (Woynarowich and Horváth, 1980)

For instance, the recommended numbers of fry to be transported in polyethylene bags according to Czechoslovak Instructions for fish-farming practices (Pecha, Berka and Kouril, 1983) are shown in Tables 3–5.

About the same standard densities of transported fish are indicated in the West German recommendation for fish transport (1979) - Tables 6–8.

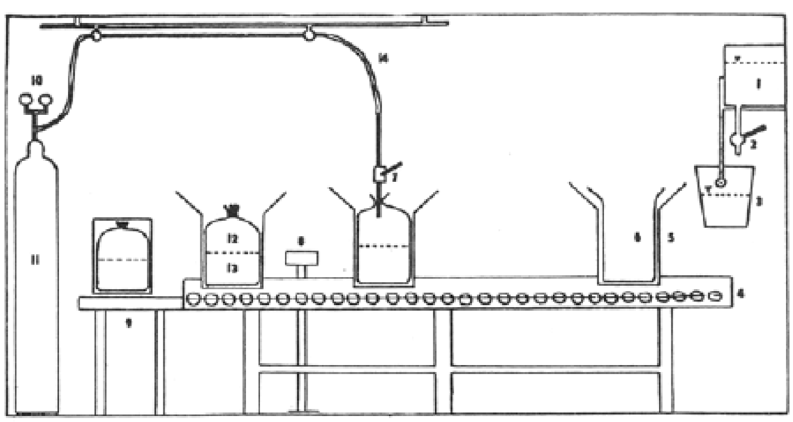


Figure 8 ispatching line of the pike hatchery of the Czech Angler's Union at Tábor (Pecha, Berka and Kouril, 1983)
1- water tank with the float system of water filling, with water aeration and tempering, 2 - filling valve, 3 - calibrated vessel with a turning joint, 4 - handling banch with rollers for carrying the boxes, 5 - cardboard box, 6 - polyethylene bag,

7 - valve for filling the bag with oxygen, 8 - rubber band magazine, 9 - packing table, 10 - cylinder pressure regulator, 11 - pressure cylinder with oxygen, 12 - oxygen atmosphere in bag, 13 - water in bag, 14 - oxygen supply from pressure cylinder to filling valve 7

Hungarian experience with specialized transport of pike-perch in closed bags is interpreted by Horváth, Tamás and Tölg, (1984). The conditions of transport are documented in Table 9.

The standards of fish fry transport published in the instructions by Orlov *et al.*, (1974) for Soviet conditions can also be considered as practically verified. The data apply to fish densities in bags, volume 40 litres, including 20 litres of water and 20 litres of oxygen, from the point of view of the possible total weight and number of fish transported; the standards are indicated for cyprinids (Tables 10 and 11), salmonids (Tables 12 and 13), for fish of the perch family (Tables 14 and 15), and for Soviet sturgeons.

Similar details concerning the transport of fish fry in polyethylene bags are given in the monograph by Kozlov *et al.*, (1977) on the acclimatization of aquatic organisms in which fish transport forms an inseparable part of the acclimatization processes.

As to other commercially important fish not separately referred to in the above tables, it should be mentioned that Snow, Brewer and Wright (1978) transported sac fry of largemouth bass. The transport distances were up to 2 500 km. The fry were kept in polyethylene bags containing 7.57 litres of water with a supply of oxygen, and the bags were protected in insulated polystyrene containers. The transport density of the fry was 3 000 per litre. To ensure that the fry would be ready to begin feeding when they were released into rearing ponds, they were shipped at 1, 2 or 3 days of age, depending on the distance of their destination. Shipments were made by commercial airline or bus, but automobiles were also successfully used.

Literature also contains other data on the transport capacity of polyethylene bags, e.g., Ioshev (1980), Kruzhalina, Leis and Ovchinnikova (1984), Bogdan (1972), and others. But a large proportion of these data lack detailed documentation on all the aspects that can substantially affect the results of transport.

3.4 General Notes on the Transport of Juvenile Fish in Bags

In the final comments on fry transport in polyethylene bags, some findings and information should be mentioned, as given generally in the relevant literature. Emphasis should be laid on the requirements to transport the fry after the absorption of food: when the fry are freshly fed the amount to be transported should be reduced by at least 50%. The water in which sac fry are transported should be kept as still as possible (the fry could be damaged in the bags). On the other hand, advanced fry and fingerlings are not affected by increased movement of the transport water. When oxygen is replaced in the bag during shipment survival increases by 20–40%; when half the water and all oxygen are replaced survival increases by 50–60%. and when all water and all oxygen are replaced the increase in survival is by 90–100% (Orlov *et al.*, 1973). Differences in the nature of each group of fishes also have a marked influence on the results of shipment: in the case of the sac fry of cyprinids the losses highly increase when temperature during transport is under 20°C, and the transport time should never be longer than 24 h; when salmonid fry are transported, longer stops during transport threaten to create an oxygen deficit. Adherence to the recommended standards of the transport of different fish groups would keep the losses of larvae below 5%, fry 3%, and yearlings 1%. There is one exception still waiting for satisfactory explanation: at temperature above 15°C the yearlings of big head may suffer up to 50% losses, despite a comparatively low transport density (Orlov *et al.*, 1973).

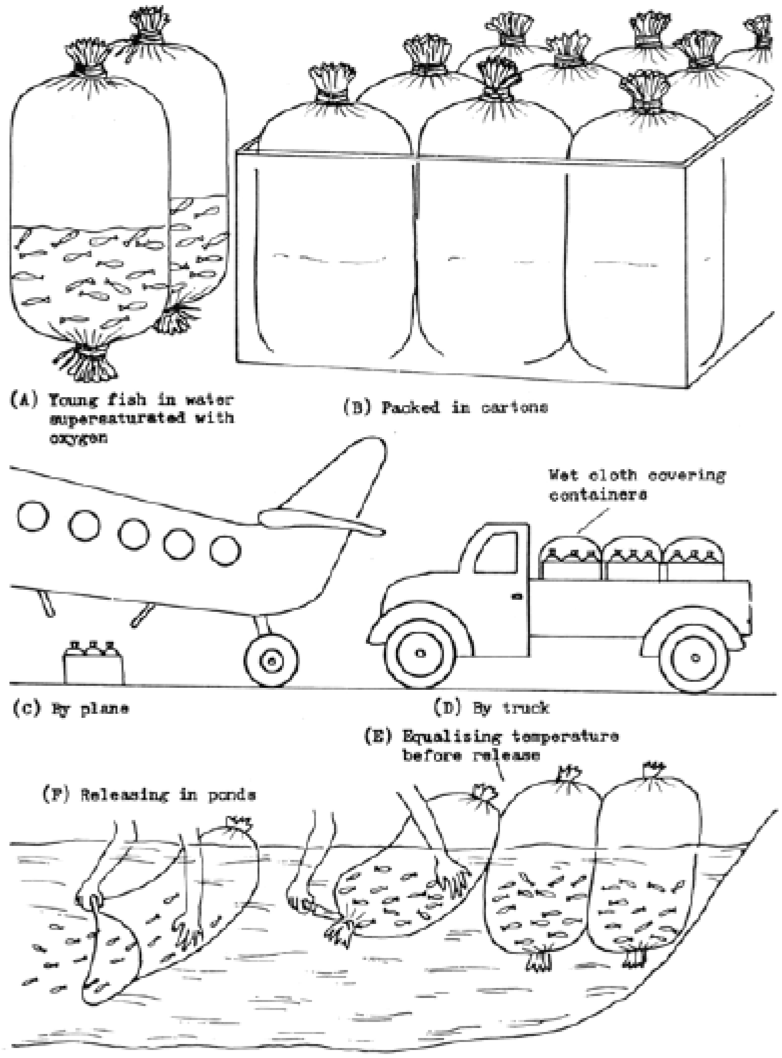
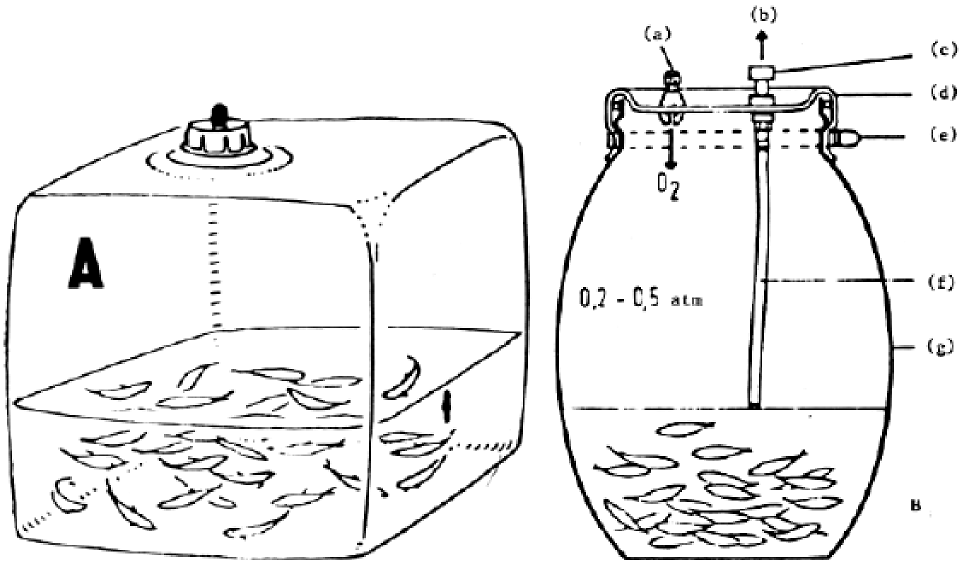


Figure 9 Transport of young fish packed in plastic bags (Woynarowich and Horváth, 1980)



(a) Aerator with screw cap; (b) Water;
(c) Water inlet with screw cap;
(d) Tight cover; (e) Tightening ring;
(f) Plastic pipe; (g) Plastic container

Figure 10 Sealed plastic containers

A - container volume 25 litres, the oxygen-inlet value is built in the screw cap;

B - container volume 50–150 litres, vertical plastic pipe keeps water at the required level (Vollmann-Schipper, 1975)

Table 3

Numbers of sac fry, in thousands, to be transported in a polyethylene bag with a volume of 50 litres, i.e., 20 litres of water and 30 litres of oxygen

Fish species	Water temperature 10°C				15°C				20°C				25°C			
	Duration of transport (in h)															
	4	8	12	24	4	8	12	24	4	8	12	24	4	8	12	24
Brown trout	20	15	10	5												
Brook trout	20	15	10	5												
Rainbow trout	25	20	15	10	20	15	10	5	15	10	5	3				
Grayling	40	30	25	20	30	25	20	15								
Lavaret	80	60	50	40												
Peled	120	80	70	60	100	60	40	30								
Pike	80	50	40	30	50	30	25	20								
Carp					200	150	100	50	120	80	60	40	100	80	60	30
Tench					100	80	60	30	60	40	30	15	60	40	30	15
Grass carp									60	50	40	30	40	30	25	15
Sheatfish									60	50	40	30	40	30	25	15
Asp					100	80	60	40	80	60	40	20				
Chub					100	80	60	40	80	60	40	20				
Barbel					100	80	60	40	80	60	40	20				
Nase					100	80	60	40	80	60	40	20				

Note: Water of 15°C is the minimal temperature level for cyprinid fishes

Table 4

Numbers of advanced fry 2–3 cm long, in thousands, to be transported in a polyethylene bag with a volume of 50 litres, i.e., 20 litres of water and 30 litres of oxygen

Fish Species	Water temperature 10°C				15°C				20°C				25°C			
	Duration of transport (in h)															
	8	12	24	48	8	12	24	48	8	12	24	48	8	12	24	48
Pike	5	3.5	3	2	3	2.5	2	1								
Pike-perch	4	3	2.5	1	3	2	2	1	2	1.5	1	0.5				
Carp					15	12	10	8	12	10	8	6	10	8	6	4
Grass carp									10	8	6	5	8	6	4	3
Sheatfish									8	6	5	3	5	4	3	2
Asp					10	8	6	4	8	6	5	3				
Chub					10	8	6	4	8	6	5	3				

Note: Every 12 h the oxygen should be replaced or the amount of fish should be reduced to 50%

Table 5

Numbers of young fish to be transported in a polyethylene bag with a volume of 50 litres, i.e., 20 litres of water and 30 litres of oxygen

Fish Species	Size of fish (cm)	Water temperature (°C)	Fish density in bag (ind.)	Total weight of fish in bag (g)	Losses (%)	Maximal time of transport (h)
Brown trout	4–6	10	500	800–1 200	-	12
Rainbow trout	9–12	10	200	2 000–2 500	-	12
	12–15	10	100	2 000–2 500	-	12
Pike	4–6	10	1 000	800–1 200	<3	24
	6–9	12	500	800–1 200	<3	12
Pike-perch	4–6	12	1 000	1 000	<1	12
	6–9	10	1 000	1 300–1 600	<1	12
	9–12	10	500	2 000–3 000	<1	8
Carp	4–6	15	1 000	2 000–3 000	<2	8

Note: Transport should not be interrupted for longer than 15 minutes

Table 6

Numbers of sac fry, in thousands, to be transported in bags containing 30 litres of water and 30 litres of oxygen

Fish Species	Water temperature 10°C				15°C				20°C				25°C		
	Duration of transport (in h)														
	2	5	8	12	2	5	8	12	2	5	8	12	2	5	8
Pike	150	100	80	50	75	50	30	20							
Carp					400[a]	300	250	200	200	150	120	100	120	100	80
Grass carp									150[a]	120	100	80	80	60	40

[a] Minimal temperature level. After 12 h of transport, the oxygen should be replaced or the amount of fry should be reduced by 25–50% according to the duration of transport

Table 7

Numbers of advanced fry 2–3 cm long, in thousands, to be transported in bags containing 30 litres of water and 20–30 litres of oxygen

Fish Species	Water temperature 10°C				15°C				20°C				25°C			
	Duration of transport (in h)															
	8	12	24	48	8	12	24	48	8	12	24	48	8	12	24	48
Pike	3.5	3	2	1.5	2.5	2	1.5	1								
Pike-perch	3	2.5	1	0.7	2	1.5	1	0.5	1	0.8	0.6	0.3				
Carp					15	12	10	8	12	10	8	6	10	8	6	5
Grass carp									10	8	6	5	8	6	4	3
Sheatfish									8	6	5	4	4	4	3	2

Note: Every 12 h, the oxygen should be replaced or the amount of fish should be reduced to 50%

Table 8

Numbers of young fish to be transported in oxygen-filled bags, volume 50 litres, oxygen:water ratio from 3:1 to 3:2

Fish Species	Size of fish (cm)	Amount of water (litre)	Water temperature (°C)	Fish density; Weight	Losses (%)	Maximal time of transport (h)
Trout	4–6	15	10	500 ind. 800–1 200 g	-	15
	9–12	10	10	100 ind. 1 500 g	-	12
	12–15	15	10	100 ind. 2 500 g	-	12
Pike	4–7	10	6–8	1 000 ind. 900–1 200 g	2	16
Pike-perch	4–6	10	10	1 000 g	1	15
	6–9	15	-	1 000 ind. 1 500 g	1	15
	9–12	15	-	1 000 ind. 1 800 g	1	15

Note: Transport should not be interrupted for longer than 30 minutes

3.5 Transport of Large Fish in Bags

Individual shipments of large brood fish can also be made in polyethylene bags. This possibility is suggested by several literary sources. The transport of brood carp and herbivorous fish from Hungary to Egypt and Iran is commented on by Varga (1984) and by Varádi and Tarnai (1983); however, it is only Orlov who published tables (Table 16) with values of the survival of large carp, herbivorous fish, pike-perch and also some sturgeons, enabling to derive some guide parameters for shipment.

3.6 General Notes on the Transport of Brood Fish in Bags

Naturally, when large fish of these species are transported for introduction or acclimatization, it is not recommended to apply the theoretical critical possibilities. The main requirement is to keep the fish healthy and physiologically intact throughout the transport, because brood fish are of a high potential value and their transport is to pay off in future. With respect to this, the safe transport densities of these fish, as recommended by Orlov *et al.*, (1974) are 5 to 10 times lower than those of the fish of the same size transported to market.

Table 9

Transport of pike-perch fry in polyethylene bags

Age group - total length	Duration of transport (h)	Plastic bag (30 lit. water + 30 lit. O_2) Temperature °C			
		10	15	20	25
Early fry of 6–7 mm (thousand)	2	100	50	40	-
	5	80	40	30	-
	10	60	25	20	-
	15	50	20	15	-
Advanced fry of 3–5 cm (thousand)	2	5	3	2	1
	5	4	2.5	1.5	0.8
	10	2.5	1.8	0.8	0.5
	15	2	1.2	0.6	0.3
One summer fingerling	2	300	250	200	-
	5	250	200	150	-
	10	200	150	100	-
	15	140	120	100	-

Note: It is not recommended to transport large fish in bags due to the possibility of bag damaging by fin rays

Table 10

The amounts in kg of cyprinid juveniles to be transported in 40-litre bags containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual weight of fish (g)	Duration of transport (in h) 5	10	15	20	25	30	35	40	45	50
5°C	5.0	3.8	3.8	3.8	3.8	3.8	3.6	3.2	2.8	2.7	2.4
	10.0	5.0	5.0	5.0	4.9	4.1	3.6	3.2	2.8	2.7	2.4
	20.0	6.0	6.0	6.0	6.0	5.6	4.8	4.4	4.0	3.6	3.4
10°C	1.0	2.0	2.0	2.0	2.0	1.9	1.6	1.4	1.2	1.1	0.9
	2.0	3.0	3.0	2.9	2.3	1.9	1.6	1.4	1.2	1.1	0.9
	5.0	3.8	3.8	3.8	3.0	2.5	2.2	1.9	1.6	1.5	1.4
	10.0	5.0	5.0	3.8	3.0	2.5	2.2	1.9	1.6	1.5	1.4
	20.0	6.0	6.0	5.2	4.2	3.5	3.0	2.6	2.4	2.2	1.9
15°C	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	0.5	1.3	1.3	1.3	1.3	1.1	1.0	0.88	0.77	0.68	0.62
	1.0	2.0	2.0	2.0	1.8	1.5	1.2	1.1	1.0	0.89	0.8
	2.0	3.0	3.0	2.3	1.8	1.5	1.2	1.1	1.0	0.89	0.8
	5.0	3.8	3.8	3.3	2.6	2.1	1.8	1.6	1.4	1.2	1.1
	10.0	5.0	4.6	3.3	2.6	2.1	1.8	1.6	1.4	1.2	1.1
	20.0	6.0	5.1	3.7	2.9	2.4	2.1	1.8	1.6	1.4	1.2
20°C	0.0015	0.15	0.083	0.083	0.075	0.075	-	-	-	-	-
	0.02–0.03	0.5	0.5	0.5	0.5	0.5	0.5	0.45	0.4	0.36	0.31
	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.57	0.51	0.46
	0.5	1.3	1.3	1.3	1.0	0.92	0.76	0.66	0.57	0.51	0.46
	1.0	2.0	2.0	1.8	1.3	1.0	0.92	0.79	0.69	0.61	0.55
	2.0	3.0	2.5	1.8	1.3	1.0	0.92	0.79	0.69	0.61	0.55
	5.0	3.8	3.4	2.5	1.9	1.6	1.3	1.1	1.0	0.93	0.83
	10.0	5.0	3.4	2.5	1.9	1.6	1.3	1.1	1.0	0.93	0.83
	20.0	6.0	4.4	3.2	2.5	2.0	1.8	1.5	1.3	1.2	1.1
25°C	0.0015	0.15	0.083	0.083	0.075	0.075	-	-	-	-	-
	0.02–0.03	0.5	0.5	0.5	0.5	0.5	0.5	0.43	0.38	0.34	0.2
	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.58	0.5	0.45	0.4
	0.5	1.3	1.3	1.3	1.0	0.8	0.66	0.58	0.5	0.45	0.4
	1.0	2.0	2.0	1.5	1.3	1.0	0.84	0.71	0.63	0.55	0.5
	2.0	3.0	2.3	1.5	1.3	1.0	0.84	0.71	0.63	0.55	0.5
	5.0	3.8	3.8	2.4	1.9	1.5	1.3	1.1	1.0	0.89	0.8
	10.0	5.0	4.0	2.4	1.9	1.5	1.3	1.1	1.0	0.89	0.8
	20.0	6.0	4.1	3.0	2.3	1.9	1.5	1.3	1.2	1.2	1.0

Table 11

The numbers of cyprinid juveniles to be transported in 40-litre bags containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual Weight of fish (g)	Duration of transport (in h) 5	10	15	20	25	30	35	40	45	50
5°C	5.0	760	760	760	760	760	720	640	560	540	440
	10.0	500	500	500	490	410	360	320	280	270	240
	20.0	300	300	300	300	280	240	220	200	180	170
10°C	1.0	2 000	2 000	2 000	2 000	1 900	1 600	1 400	1 200	1 100	900
	2.0	1 500	1 500	1 450	1 150	950	800	700	600	550	450
	5.0	760	760	760	600	500	440	380	320	300	280
	10.0	500	500	380	300	250	220	190	160	150	140
	20.0	300	300	260	210	175	150	130	120	110	95
15°C	0.2	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
	0.5	2 600	2 600	2 600	2 600	2 200	2 000	1 760	1 540	1 360	1 240
	1.0	2 000	2 000	2 000	1 800	1 500	1 200	1 100	1 000	890	800
	2.0	1 500	1 500	1 150	900	750	600	550	500	445	400
	5.0	760	760	660	520	420	360	320	280	240	220
	10.0	500	460	330	260	210	180	160	140	120	110
	20.0	300	255	185	145	120	105	90	80	70	60
20°C	0.0015	100 000	55 000	55 000	50 000	50 000	-	-	-	-	-
	0.02–0.03	25 000	25 000	25 000	25 000	25 000	25 000	22 500	20 000	18 000	15 550
		17 000	17 000	17 000	17 000	17 000	17 000	15 000	13 300	12 000	10 300
	0.2	3 000	3 000	3 000	3 000	3 000	3 000	3 000	2 850	2 550	2 300
	0.5	2 600	2 600	2 600	2 000	1 840	1 520	1 320	1 140	1 020	920
	1.0	2 000	2 000	1 800	1 300	1 000	920	790	690	610	550
	2.0	1 500	1 250	900	650	500	460	395	345	305	275
	5.0	760	680	500	380	320	260	220	200	186	166
	10.0	500	340	250	190	160	130	110	100	93	83
	20.0	300	220	160	125	100	90	75	65	60	55
25°C	0.0015	100 000	55 000	55 000	50 000	50 000	-	-	-	-	-
	0.02–0.03	25 000	25 000	25 000	25 000	25 000	25 000	21 500	19 000	17 000	15 000
		17 000	17 000	17 000	17 000	17 000	17 000	14 500	12 500	11 500	10 000
	0.2	3 000	3 000	3 000	3 000	3 000	3 000	2 900	2 500	2 250	2 000
	0.5	2 600	2 600	2 600	2 000	1 600	1 320	1 160	1 000	900	800
	1.0	2 000	2 000	1 500	1 300	1 000	840	710	630	550	500
	2.0	1 500	1 150	750	650	500	420	355	315	275	250
	5.0	760	760	480	380	300	260	220	200	178	160
	10.0	500	400	240	190	150	130	110	100	89	80
	20.0	300	205	150	115	95	75	65	60	55	50

Table 12

The amounts in kg of salmonid juveniles to be transported in 40-litre bags containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual Weight of fish (g)	Duration of transport (in h) 5	10	15	20	25	30	35	40	45	50
5°C	0.0012–0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.5	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	2.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.95	0.91	0.83
	10.0	1.5	1.5	1.5	1.5	1.5	1.3	1.1	0.95	0.91	0.83
	20.0	1.8	1.8	1.8	1.8	1.8	1.5	1.4	1.2	1.1	1.0
10°C	0.0012–0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.45	0.4
	2.0	0.7	0.7	0.7	0.7	0.7	0.66	0.57	0.5	0.45	0.4
	5.0	1.0	1.0	1.0	1.0	0.87	0.73	0.63	0.55	0.48	0.44
	10.0	1.5	1.5	1.4	1.0	0.87	0.73	0.63	0.55	0.48	0.44
	20.0	1.8	1.8	1.5	1.1	0.91	0.8	0.69	0.6	0.54	0.48
15°C	0.0012–0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.18	0.16
	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.27	0.24
	1.0	0.5	0.5	0.5	0.5	0.5	0.44	0.38	0.33	0.3	0.27
	2.0	0.7	0.7	0.7	0.66	0.53	0.44	0.38	0.33	0.3	0.27
	5.0	1.0	1.0	1.0	0.8	0.64	0.53	0.46	0.4	0.36	0.32
	10.0	1.5	1.5	1.0	0.8	0.64	0.53	0.46	0.4	0.36	0.32
	20.0	1.7	1.7	1.2	0.92	0.74	0.61	0.53	0.46	0.41	0.37

Table 13

The numbers of salmonid juveniles to be transported in 40-litre bags
containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual Weight of fish (g)	Duration of transport (in h)									
		5	10	15	20	25	30	35	40	45	50
5	0.0012–0.2	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700
		1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
	0.5	600	600	600	600	600	600	600	600	600	600
	1.0	500	500	500	500	500	500	500	500	500	500
	2.0	350	350	350	350	350	350	350	350	350	350
	5.0	200	200	200	200	200	200	200	190	182	166
	10.0	150	150	150	150	150	130	110	95	91	83
	20.0	90	90	90	90	90	75	70	60	55	50
10	0.0012–0.2	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700
		1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
	0.5	600	600	600	600	600	600	600	600	600	600
	1.0	500	500	500	500	500	500	500	500	450	400
	2.0	350	350	350	350	350	330	285	250	225	200
	5.0	200	200	200	200	174	146	126	110	96	88
	10.0	150	150	140	100	87	73	63	55	48	44
	20.0	90	90	75	55	45	40	34	30	27	24
15	0.0012–0.2	166 700	166 700	166 700	166 700	166 700	166 700	166 700	166 700	150 000	133 000
		1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	900	800
	0.5	600	600	600	600	600	600	600	600	540	480
	1.0	500	500	500	500	500	440	380	330	300	270
	2.0	350	350	350	330	265	220	190	165	150	135
	5.0	200	200	200	160	128	106	92	80	72	64
	10.0	150	150	100	80	64	53	46	40	36	32
	20.0	85	85	60	46	37	30	26	23	20	18

Table 14

The amounts in kg of juveniles of the perch family to be transported in 40-litre bags containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual Weight of fish (g)	Duration of transport (in h)									
		5	10	15	20	25	30	35	40	45	50
5	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	5.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.97
	20.0	1.5	1.5	1.5	1.5	1.5	1.5	1.3	1.1	1.0	0.97
	50.0	1.8	1.8	1.8	1.8	1.8	1.8	1.6	1.4	1.3	1.2
10	0.0004–0.0009	0.1	0.085	0.075	0.06	0.05	-	-	-	-	-
	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.57
	5.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.63	0.57
	10.0	1.0	1.0	1.0	1.0	1.0	1.1	0.91	0.8	0.71	0.64
	20.0	1.5	1.5	1.5	1.5	1.2	1.0	0.91	0.8	0.71	0.64
	50.0	1.8	1.8	1.8	1.7	1.4	1.1	1.0	0.91	0.81	0.73
15	0.0004–0.0009	0.1	0.985	0.075	0.06	0.05	-	-	-	-	-
	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.54	0.48	0.43
	5.0	0.8	0.8	0.8	0.8	0.8	0.72	0.61	0.54	0.48	0.43
	10.0	1.0	1.0	1.0	1.0	0.94	0.78	0.67	0.59	0.52	0.47
	20.0	1.5	1.5	1.5	1.1	0.94	0.78	0.67	0.59	0.52	0.47
	50.0	1.8	1.8	1.8	1.3	1.0	0.93	0.8	0.7	0.62	0.56
20	0.0004–0.0009	0.1	0.085	0.075	0.06	0.05	-	-	-	-	-
	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.36	0.32
	2.0	0.6	0.6	0.6	0.6	0.6	0.53	0.46	0.4	0.36	0.32
	5.0	0.8	0.8	0.8	0.8	0.68	0.57	0.49	0.43	0.38	0.34
	10.0	1.0	1.0	1.0	0.9	0.72	0.6	0.51	0.45	0.4	0.36
	20.0	1.5	1.5	1.1	0.9	0.72	0.6	0.51	0.45	0.4	0.36
	50.0	1.8	1.8	1.4	1.0	0.9	0.75	0.64	0.56	0.5	0.45
25	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	1.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.36	0.32	0.29
	2.0	0.6	0.6	0.6	0.6	0.58	0.48	0.41	0.36	0.32	0.29
	5.0	0.8	0.8	0.8	0.75	0.6	0.5	0.43	0.38	0.33	0.3
	10.0	1.0	1.0	1.0	0.8	0.64	0.53	0.46	0.4	0.36	0.32
	20.0	1.5	1.5	1.0	0.8	0.64	0.53	0.46	0.4	0.36	0.32
	50.0	1.8	1.8	1.3	1.0	0.8	0.68	0.58	0.5	0.46	0.41

Table 15

The numbers of juveniles of the perch family to be transported in 40-litre bags containing 20 litres of water and 20 litres of oxygen

Temperature (°C)	Individual Weight of fish (g)	Duration of transport (in h) 5	10	15	20	25	30	35	40	45	50
5	0.2	500	500	500	500	500	500	500	500	500	500
	0.5	400	400	400	400	400	400	400	400	400	400
	1.0	400	400	400	400	400	400	400	400	400	400
	2.0	300	300	300	300	300	300	300	300	300	300
	5.0	160	160	160	160	160	160	160	160	160	160
	10.0	100	100	100	100	100	100	100	100	100	97
	20.0	75	75	75	75	75	75	65	55	50	48
	50.0	36	36	36	36	36	36	32	28	26	24
10	0.0004–0.0009	250 000	212 500	187 500	150 000	125 000	-	-	-	-	-
		111 000	94 500	83 500	66 500	55 500					
	0.2	500	500	500	500	500	500	500	500	500	500
	0.5	400	400	400	400	400	400	400	400	400	400
	1.0	400	400	400	400	400	400	400	400	400	400
	2.0	300	300	300	300	300	300	300	300	300	285
	5.0	160	160	160	160	160	160	160	160	126	114
	10.0	100	100	100	100	100	100	90	80	71	64
	20.0	75	75	75	75	60	50	45	40	35	32
	50.0	36	36	36	34	28	22	20	18	16	14
15	0.0004–0.0009	250 000	212 500	187 500	150 000	125 000	-	-	-	-	-
		111 000	94 500	83 500	66 500	55 500					
	0.2	500	500	500	500	500	500	500	500	500	500
	0.5	400	400	400	400	400	400	400	400	400	400
	1.0	400	400	400	400	400	400	400	400	400	400
	2.0	300	300	300	300	300	300	300	270	240	215
	5.0	160	160	160	160	160	144	122	108	96	86
	10.0	100	100	100	100	94	78	67	59	52	47
	20.0	75	75	75	55	47	39	33	29	26	23
	50.0	36	36	36	26	20	18	16	14	12	11
20	0.0004–0.0009	250 000	212 500	187 500	150 000	125 000	-	-	-	-	-
		111 000	94 500	83 500	66 500	55 500					
	0.2	500	500	500	500	500	500	500	500	500	500
	0.5	400	400	400	400	400	400	400	400	400	400
	1.0	400	400	400	400	400	400	400	400	360	320
	2.0	300	300	300	300	300	265	230	200	180	160
	5.0	160	160	160	160	134	114	98	86	76	68
	10.0	100	100	100	90	72	60	51	45	40	36
	20.0	75	75	55	45	36	30	25	22	20	18
	50.0	36	36	28	20	18	15	13	11	10	9
25	0.2	500	500	500	500	500	500	500	500	500	500
	0.5	400	400	400	400	400	400	400	400	400	400
	1.0	400	400	400	400	400	400	400	360	320	290
	2.0	300	300	300	300	290	240	205	180	160	145
	5.0	160	160	160	150	120	100	86	76	66	60
	10.0	100	100	100	80	64	53	46	40	36	32
	20.0	75	75	50	40	32	26	23	20	18	16
	50.0	36	36	26	20	16	14	12	10	9	8

Table 16

Basic parameters of polyethylene bags and survival of large individuals of some important fish (in h)

(a) Carp

Individual Weight of fish (kg)	Length of fish (cm)	Length of bag (cm)	Volume of bag (lit.)	Amount of water (lit.)	Amount of oxygen (lit.)
1	37	65	40	19	20
2	46	65	40	18	20
3	53	65	40	17	20
4	58	65	40	16	20
5	63	73	45	17	23
6	67	77	47	17	24
7	70	80	49	17	25
8	74	84	52	18	26
9	76	86	53	17	27
10	79	89	87	33	44
15	91	101	99	34	50
20	100	110	108	34	54

Individual Weight of fish (kg)	Water temperature (°C)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1															116	108	101	95	89	82	78
2						121	117	101	89	84	76	69	63	61	56	52	49	46	43	40	38
3				110	100	90	76	66	58	55	49	45	41	40	37	34	32	30	28	26	25
4		106	92	80	73	65	55	48	42	40	36	33	30	29	27	25	23	22	21	19	18
5	110	94	82	71	65	58	49	42	37	35	32	29	27	26	23	22	20	19	18	17	16
6	94	80	70	61	55	50	42	36	32	30	27	25	23	22	21	20	18	17	16	14	14
7	83	71	62	53	48	44	37	32	29	27	24	22	20	19	19	17	16	15	14	13	12
8	76	65	56	49	44	40	33	29	26	24	22	20	18	18	17	15	14	13	13	12	11
9	67	58	50	43	40	36	30	26	23	22	20	18	16	16	15	14	13	12	11	10	10
10	106	91	79	68	62	56	47	41	36	34	31	28	26	25	23	21	20	19	18	16	15
15	77	66	57	49	45	41	34	30	26	24	22	20	19	18	17	15	14	14	13	12	11
20	61	52	45	39	36	32	27	23	21	20	18	16	15	14	13	12	11	11	10	9	9

(b) Grass carp

Individual weight of fish (kg)	Length of fish (cm)	Length of bag (cm)	Volume of bag (lit.)	Amount of water (lit.)	Amount of oxygen (lit.)
1	39	65	40	19	20
2	49	65	40	18	20
3	56	65	40	17	20
4	62	72	44	18	22
5	67	77	47	18	24
6	71	81	50	19	25
7	74	84	52	19	26
8	77	87	54	19	27
9	81	91	56	19	28
10	84	94	92	36	46
15	95	105	103	36	52
20	105	115	113	36	57
25	114	124	122	36	61
30	121	131	129	34	65

Individual Weight of fish (kg)	Water temperature (°C)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1															116	108	100	95	89	82	78
2							117	101	89	84	76	69	63	61	56	52	49	46	43	40	38
3				110	100	90	76	66	58	55	49	45	41	40	37	34	32	30	28	26	25
4		118	103	89	81	73	62	53	47	44	40	36	33	32	30	28	26	24	23	21	20
5	116	99	86	75	68	61	52	45	40	37	34	31	28	27	25	23	22	20	19	18	17
6	101	86	75	65	59	53	45	39	35	33	29	27	24	23	22	20	19	18	17	15	15
7	89	76	66	57	52	47	40	34	30	29	26	23	21	20	19	18	17	16	15	14	13
8	79	68	59	51	47	42	35	34	27	26	23	21	19	18	17	16	15	14	13	12	12
9	72	61	54	46	43	38	32	28	25	23	21	19	18	17	16	15	14	13	12	11	10
10	113	96	84	73	66	60	50	44	39	36	33	30	27	26	24	23	21	20	19	17	16
15	81	69	60	52	47	43	36	31	31	26	23	21	20	19	17	16	15	14	13	12	12
20	64	55	48	41	38	34	27	24	21	20	19	17	16	15	14	13	12	11	11	10	9
25	54	46	40	34	31	28	24	21	18	17	16	14	13	12	11	11	10	9	9	8	8
30	46	39	34	29	27	24	20	18	16	15	13	12	11	11	10	9	9	8	8	7	7

(c) Bighead carp

Individual weight of fish (kg)	Length of fish (cm)	Length of bag (cm)	Volume of bag (lit.)	Amount of water (lit.)	Amount of oxygen (lit.)
1	40	65	40	19	20
2	50	65	40	18	20
3	57	65	40	17	20
4	63	73	45	18	23
5	68	78	48	19	24
6	72	82	50	19	25
7	76	86	53	19	27
8	80	90	55	19	28
9	83	93	57	19	29
10	86	96	4	37	47
15	98	108	106	38	53
20	107	117	115	37	58
25	116	126	124	37	62
30	123	133	130	35	65

Individual Weight of fish (kg)	Water temperature (°C)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1													114	109	101	94	88	83	78	72	68
2						121	102	89	78	74	67	60	55	53	49	46	43	40	38	35	33
3			111	96	87	78	66	58	51	48	43	39	36	35	32	30	28	26	25	23	22
4		106	92	80	72	65	55	48	42	40	36	33	30	29	27	25	23	22	21	19	18
5	109	93	81	70	64	57	48	42	37	35	32	29	26	25	23	22	20	19	18	17	16
6	89	75	66	57	52	47	39	34	30	29	26	23	21	21	19	18	17	16	15	14	13
7	79	68	59	51	46	42	35	31	27	26	23	21	19	18	17	16	15	14	13	12	12
8	71	60	53	46	42	37	32	27	24	23	21	19	17	16	15	14	13	12	12	11	10
9	64	55	48	41	38	34	29	25	22	21	19	17	16	15	14	13	12	11	11	10	9
10	101	86	75	65	59	53	45	39	35	33	29	27	25	24	22	20	19	18	17	15	15
15	73	62	54	47	43	39	33	28	26	24	21	19	18	17	16	15	14	13	12	11	11
20	57	49	43	37	34	30	26	22	19	18	17	15	14	13	12	11	11	10	10	9	8
25	48	41	36	31	28	25	21	18	16	15	14	13	12	11	10	10	9	8	8	7	7
30	40	34	29	26	24	21	18	16	14	13	12	11	10	9	9	8	8	7	7	6	6

(d) Pike-perch

Individual weight of fish (kg)	Length of fish (cm)	Length of bag (cm)	Volume of bag (lit.)	Amount of water (lit.)	Amount of oxygen (lit.)
1	40	65	40	19	20
2	50	65	40	18	20
3	58	65	40	17	20
4	65	75	46	19	23
5	70	80	49	19	25
6	75	85	52	20	26
7	78	88	54	20	27
8	83	93	57	20	29
9	86	96	59	20	30
10	90	100	62	21	31

Individual weight of fish (kg)	Water temperature (°C)																				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	114	98	85	76	68	62	57	55	51	47	46	44	41	40	39	37	34	33	31	30	28
2	55	48	42	37	33	30	28	27	25	23	22	22	20	20	19	18	17	16	15	15	14
3	36	31	27	24	22	20	18	17	16	15	14	14	13	13	12	12	11	10	10	9	9
4	31	26	23	20	18	17	15	15	14	13	12	12	11	11	11	10	9	9	8	8	8
5	26	22	19	17	15	14	13	12	11	11	10	10	9	9	9	8	8	7	7	7	6
6	22	19	17	15	13	12	11	11	10	9	9	9	8	8	8	7	7	6	6	6	6
7	20	17	15	13	12	11	10	9	9	8	8	8	7	7	7	6	6	6	6	5	5
8	18	15	13	12	11	10	9	9	8	7	7	7	7	6	6	6	5	5	5	5	5
9	16	14	12	11	10	9	8	8	7	7	7	6	6	6	6	5	5	5	4	4	4
10	15	13	11	10	9	8	7	7	7	6	6	6	6	5	5	5	4	4	4	4	4

The general principles, as recommended by a number of authors, e.g., Woynarowich and Horváth (1980); Pecha, Berka and Kouril (1983) and others, are that in every specific case the existing conditions and circumstances should always be considered and that the guide parameters should be adjusted on the basis of preliminary trials.

4. OPEN SYSTEMS OF FISH TRANSPORT

The open systems have many technical variants, ranging from small transport fish-cans, containers for fish transport within the territory of a fish farm, up to special fish transport trucks and tank wagons.

4.1 General Technological Notes

In all cases of fish transport in open systems, it should be borne in mind that even a short-time transport of 10–30 m in open plastic or metal tanks should be done under the conditions of constant air or oxygen supply. This is very important to the welfare of fish even if dissolved oxygen content of water seems to be satisfactorily high in the tank. Transport longer than half an hour should be in completely filled and closed tanks to prevent splashing and injuries to young fish bumping into each other in the well of the tank.

The weight of fish that can be safely transported in a tank depends on the efficiency of the aeration system, duration of the transport, water temperature, fish size and fish species.

If environmental conditions are constant, the carrying capacity of a transport unit depends upon fish size. It has been suggested that the maximum permissible weight of trout in a given tank is directly proportional to their length. Thus, if a tank can safely hold 50 kg of 5 cm trout, it could hold 100 kg of 10 cm trout, and 150 kg of 15 cm trout (Piper *et al.*, 1982).

Reported loading rates for fish vary widely among farms, and maximum carrying capacities of different types of transport units have not been determined.

Some calculations of loading rates for various fish species are presented by Piper *et al.*, (1982). Under ideal conditions, the maximum load of 20–28 cm rainbow trout is 3–3.1 kg/litre of water for 8 to 10 h. Similar loading rates are appropriate for brook, brown, and lake trout of the same size. Channel catfish can be safely transported at loadings presented in Table 17. If the trip exceeds 16 h, it is recommended that a complete water change be made during transport.

Table 17

Weight (in kg) of channel catfish that can be transported per litre of 18°C water (Piper *et al.*, 1982)

Number of fish (per kg)	Transit period (in h)		
	8	12	16
2	0.75	0.66	0.57
4	0.71	0.57	0.41
9	0.60	0.49	0.35
110	0.41	0.30	0.24
276	0.35	0.26	0.21
552	0.26	0.21	0.18
1 100	0.21	0.20	0.15
2 200	0.15	0.12	0.08
22 000	0.02	0.02	0.02

The following guidelines may be of value for transporting channel catfish (Piper *et al.*, 1982):

- 0.5 kg of 40 cm channel catfish can be transported per litre of water at 18°C;
- loading rates can be increased by 25% for each 5°C decrease in water temperature, and reduced proportionately for an increase in temperature;
- as fish length increases, the weight of fish per litre of water can be increased proportionally for an increase in temperature. For example, a tank holding 120 g of 10 cm catfish will safely hold 250 g of 20 cm or 500 g of 40 cm fish per litre of water;
- if the transport time exceeds 12 h, the loading rate should be decreased by 25 percent;
- if the transport time exceeds 16 h, loading rates should be decreased by 50 percent or a complete water change should be arranged;
- during the winter, transporting temperature of 7–10°C are preferred, whereas 15–21°C are preferable during summer months.

Table 18 suggests loading rates that have proved successful for northern pike and walleye.

Table 18

Weight (in kg) of northern pike and walleye that can be carried per litre of water at temperatures between 13–18°C (Piper *et al.*, 1982)

Size of fish (cm)	kg of fish per litre	Transit period (h)
7.6	0.15	8.0
5.1	0.08	8.0
2.5	0.07	8.0

From the technical point of view, most tanks constructed in recent years are insulated, usually with styrofoam, fiberglass or urethane. Styrofoam and urethane are preferred materials because of their superior insulating qualities and the minimal effect that moisture has on them. A well-insulated tank minimizes the need for elaborate temperature-control systems and small amounts of ice can be used to control the limited heat rises.

Circulation is needed to maintain well-aerated water in all parts of the tank. Transport success is related to tank shape, water circulation pattern, aerator type and other design criteria. Warmwater transport tanks may be compartmented. Compartments facilitate fish stocking at several different sites on a single trip, permit separation of species, and act as baffles to prevent water surges. Tanks in current use have 1 000–2 700 litre capacities, averaging about 1 700 litres. However, 4 500 litre tanks occasionally are used in the USA to transport catchable size catfish, trout and bass (Piper *et al.*, 1982).

Although most tanks presently in use are rectangular, the trend in recent years has been towards elliptical tanks, such as those used to transport milk. This shape has several advantages: V-shaped, elliptical or partially round tanks promote better mixing and recirculation of water as the size of the tank increases. This shape also conforms to a truck chassis and holds the centre of gravity towards the area of greatest strength.

Water circulation systems are of various sizes and designs. Suction lines to the pumps lie on the bottom of the tank and are covered by perforated screens. Water is carried to the pumps and then forced through overhead spray heads mounted above the waterline. In most systems, oxygen is introduced in one of the suction lines just ahead of the pump. This usually is controlled by a medical gas-flow meter; because of the danger involved in handling and transporting bottled oxygen, care must be taken to follow all prescribed safety procedures.

Self-priming pumps powered by gasoline engines are used to circulate water in many transport units. Pumps may be close-coupled or flexibly coupled. Although the former type is more compact, it tends to transfer heat to the water. Depending upon ambient air temperature, close-coupled pumps may increase the temperature of 1 500 litres of water by about 4°C an hour, whereas flexible coupling will reduce heat transfer to approximately 1.7°C per hour (Piper *et al.*, 1982).

A method of circulating water with 12-volt mechanical aerators uses carbon rods and micropore tubing for dispensing oxygen. Aerators alone may not be sufficient to provide the oxygen needed to transport large loads of fish, but a supplemental oxygenation system can increase the carrying capacity of the transport tank. Some advantages of aerator systems over gasoline-driven water pump systems are (Piper *et al.*, 1982):

- Temperature increases from aerators are less than 0.5°C per hour, compared with 1.3°C with pumps;
- aerators and the oxygen injection system can operate independently. There are advantages to carrying small sizes of certain species of fish on oxygen alone. Oxygen also can be used as a temporary backup system if aerators fail;
- usually, aerators have fewer maintenance problems;
- costs of recirculating equipment and aerators strongly favor aerators;
- use of aerators eliminates the space required between the tank and truck cab for pumps and plumbing.

The most efficient tanks have the highest water circulation rates, but circulation rates must be balanced with water capacity. Pumping or aerating systems should be able to circulate at least 40 percent of the tank water per minute when 20–22 cm salmonids are transported, though lesser rates are appropriate for smaller fish (Piper *et al.*, 1982).

4.2 Technical Designs of Transport Units

4.2.1 Small Transport Units

The survey of the technical designs of the open systems of fish transport can be started from a small fish can (Fig. 11), described by Gilev and Krivodanova (1984). Its volume is 39 litres, transport time without replacement of the oxygen cylinder 30 hours, oxygen cylinder capacity 2 litres, full can weight 53.5 kg. The oxygen is conducted from the cylinder into porous distributor installed in can bottom to oxygenate the water with the fish.

The small transport container for fish fry or for a small number of trout (Vollmann-Schipper, 1975) is similar to the can. Its volume is from 50 to 150 litres, oxygen is conducted from the cylinder into the porous distributor in container bottom (Fig. 12).

Aeration grates connected with separate sources of air, e.g., compressors or oxygen are usually installed in the bottoms of the larger containers (Fig. 13 and 14).

The transport tanks for internal transports inside the fish farm are supplied without the top closure (Fig. 15). Their volume is from 200 to 1 000 litres. A removable gutter is used for releasing the fish through the sluice. Tanks for internal transports, commercially produced by the Ewos Company, are shown in Fig. 16.

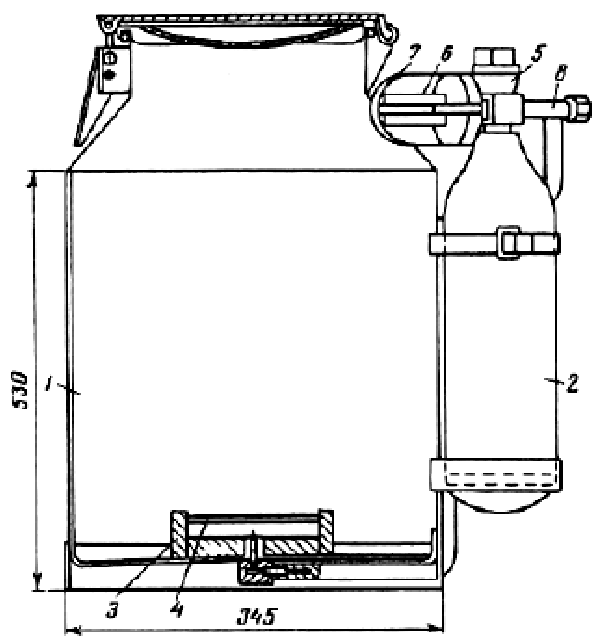
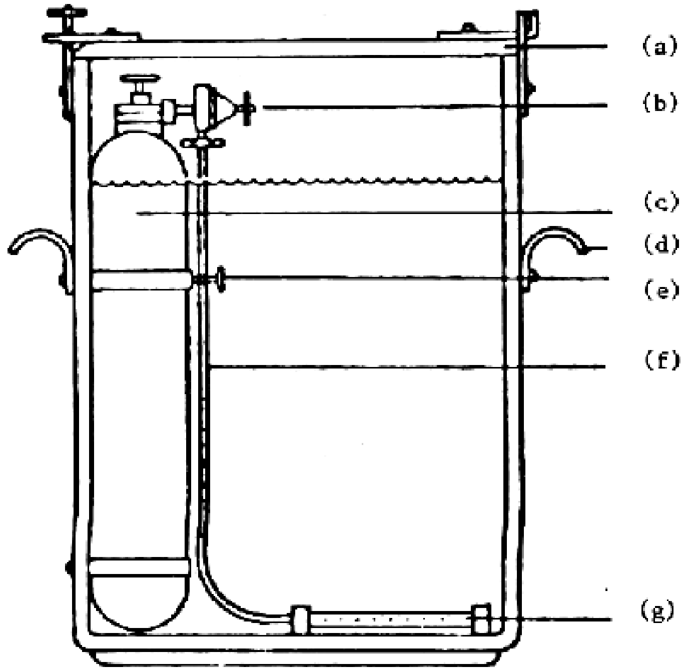


Figure 11 Fish fry transport can (Gilev and Krivodanova, 1984)

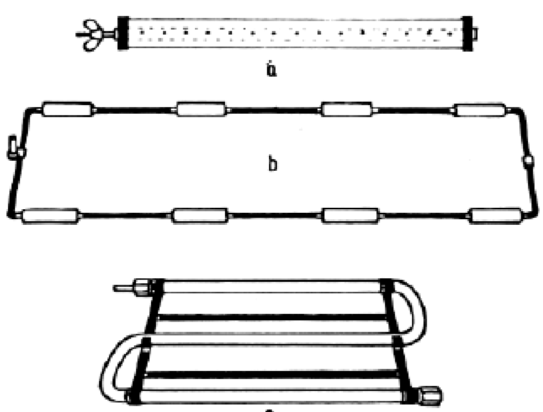


(a) Removable cover; (b) Reduction valve;
(c) Oxygen tank (5–7 lit.); (d) Handle; (e) Support;
(f) Pressure piping; (g) Aeration device.

Figure 12 Small transport container for fish fry or trout (Vollmann-Schipper, 1975)

Small transport tanks, usually of glass-reinforced plastic, which can be transported in a passenger car are used with success for the transport of small amounts of fish (Fig. 17). The commercial product of Tess Aquaculture Ltd., shown in Fig. 18, is an example of such a tank. The tank has a separate pump, managed from the electrical system in car, with a capacity of 1 800 litres of water/hour; it keeps good oxygen conditions for the fish.

Small amounts of fish can also be transported by passenger-car trailers on which the fish tank is divided into two compartments. The trailer also has a compressed oxygen cylinder. It may also be equipped with a non-traditional tank of plastic foil, suspended on a tubular frame (Fig. 19). The commercial product - a passenger-car trailer for fish transport - of Grice and Young Ltd. is shown in Fig. 20.



(a) pumice-filled tube; (b) ceramic distributors; (c) porous hose.

Figure 13 Aeration grates of transport tanks (Vollmann-Schipper, 1975)

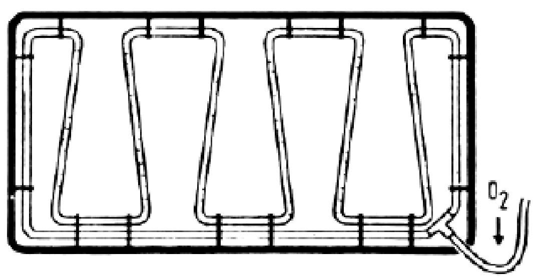


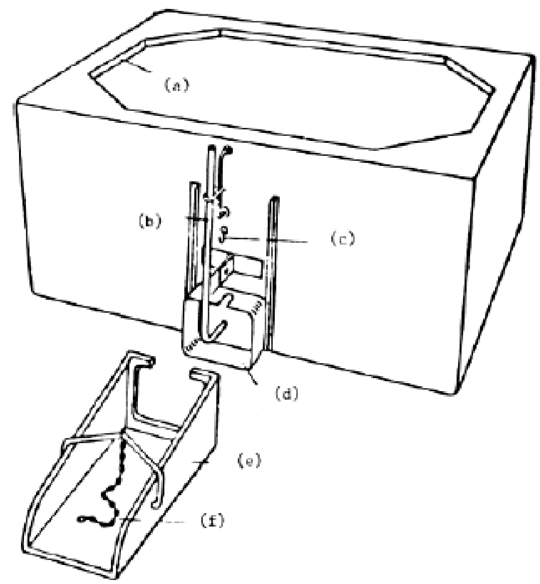
Figure 14 Aeration grate of a transport tank (Vollmann-Schipper, 1975)

Porous PVC hose fitted in a frame corresponding to the size of the tank

4.2.2 Large Transport Tanks

Large transport tanks are produced in a great variety of types. The tanks can be equipped with aeration grates, double bottoms, filters and water distributors, separate aerators, thermally insulated walls and the like. Large tanks may have a valve at the bottom for draining the water with mud. The general diagram of these tanks is shown in Fig. 21, i.e., tank with a big sluice, requiring a removable gutter for releasing the fish, and Fig. 22, i.e., tank with an outlet hopper and own discharge hose. The size of the hopper and the hose should be adjusted to the size of fish. The diameter of the hopper and the hose should be 30–40 cm in case of fingerling and 20–30 cm in case of fry, and 50–60 cm for fish larger than 1 kg in weight (Horváth, Tamás and Tölg, 1984).

There is a whole range of commercial producers of these fish transport tanks. Figures 23 to 30 show only some of their products.



(a) Protection against splashing; (b) Draining device with rocking plate; (c) Hook for chain; (d) Protruding collar for attachment of neck; (e) Draining neck; (f) Fixing chain

Figure 15 Tank for internal transport (Vollmann-Schipper, 1975)

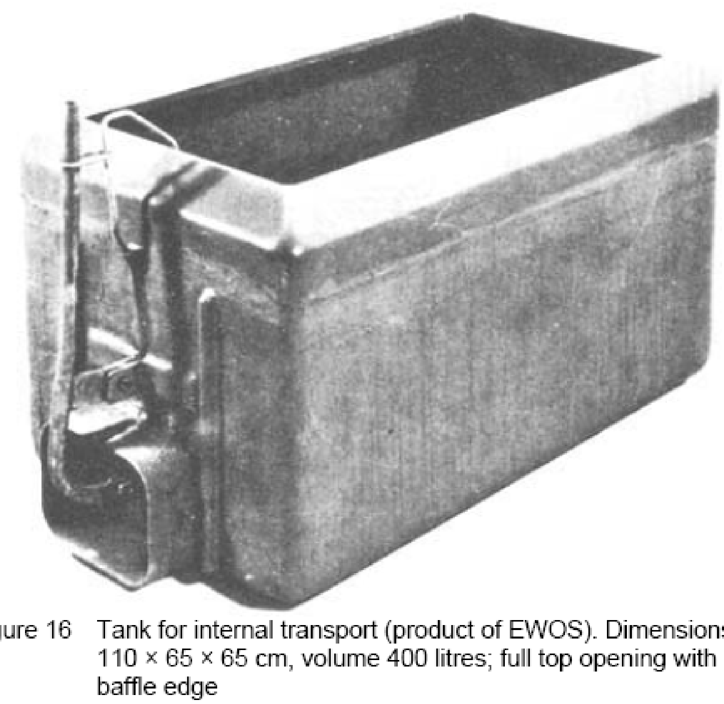
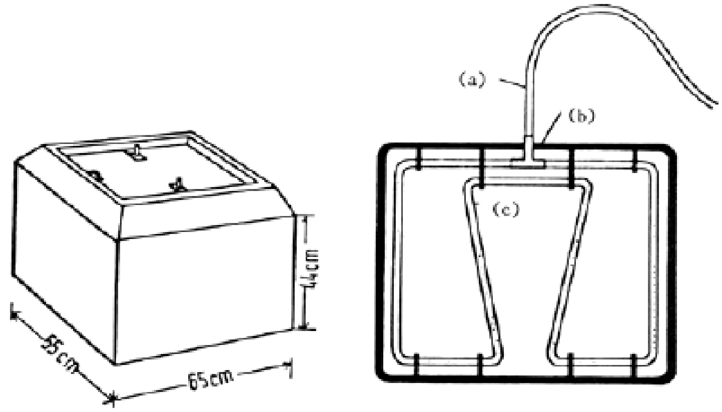


Figure 16 Tank for internal transport (product of EWOS). Dimensions: 110 × 65 × 65 cm, volume 400 litres; full top opening with baffle edge



(a) Aeration tube with T- joint; (b) Metal frame (ab. 50 × 60 cm);
(c) Perforated plastic pipe

Figure 17 Small tank to be carried in a car (Vollmann-Schipper, 1975). Container volume 100–150 litres; the aeration grate is adjusted to fit the dimensions of the tank

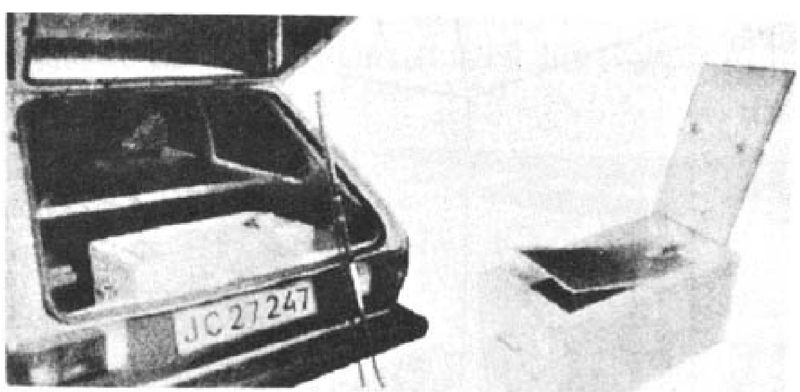
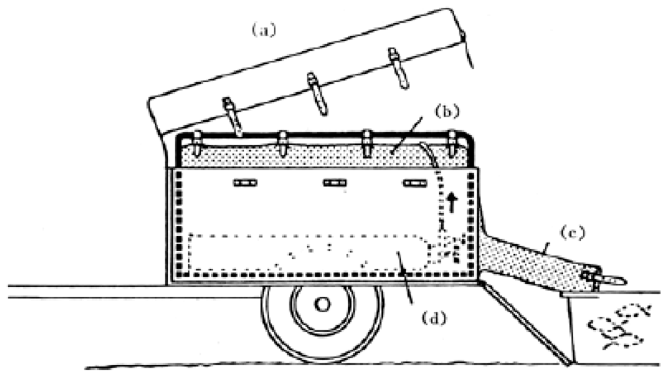


Figure 18 Mini transport tank (product of TESS); dimensions: 80 × 37 × 39 cm; weight 9 kg, pump 12 volts



(a) Flexible cover; (b) PVC - Chamber; (c) Draining tube; (d) Oxygen

Figure 19 Passenger-car trailer for fish transport (Vollmann-Schipper, 1975)

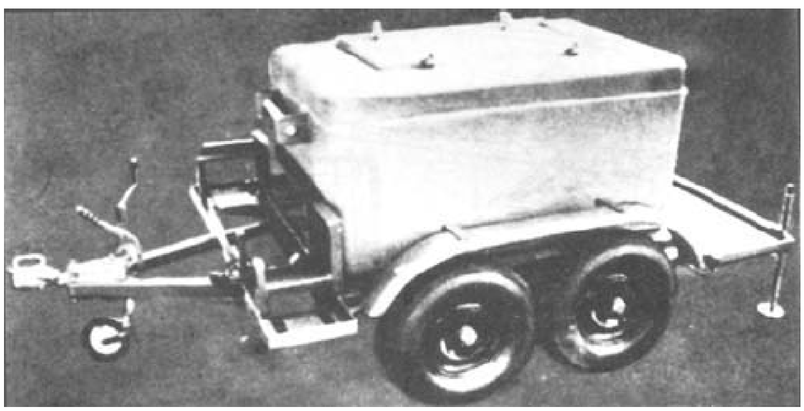


Figure 20 Passenger-car trailer for fish transport (product of GRICE and YOUNG Ltd., England)

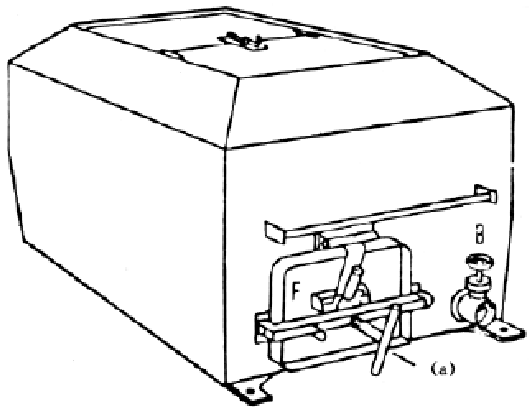


Figure 21 Transport tank of volume usually larger than 1 000 litres; F - big sluice; B - value at bottom for water replacement. (a) Tightening handle (Vollmann-Schipper, 1975)

Large tanks used in the USA usually have two compartments with a maximum volume of 2 × 1 m^3 (Fig. 31), as described by Okoniewski (1975). Each compartment can be handled separately, or both can be connected, on the other hand, by pulling out the partition. The tank can be equipped with up to six aerators (Fig. 32), three in each compartment.

A transport tank with four compartments is presented in Fig. 33.

These transport tanks are installed on trucks (Fig. 34) and are complemented by life-support equipment (air, gaseous oxygen, liquid oxygen). Separate tanks are useful for transporting several species or sizes of fish. It is recommended to fill the space between tanks with insulating polystyrene foam.

4.2.3 Single-purpose Transport Trucks

Special single-purpose trucks are also built for fish transport. For instance, Leitritz and Lewis, 1976, Californian fish farmers, use vehicles with four sizes of tanks - 11 400, 5 400, 2 700 and 1 800 litres - for fish distribution (Figures 35–38). All tanks are insulated so that temperatures can be held more constant. The three larger tanks have refrigerating units; ice is used for temperature control in the smallest unit. The newer tank trucks are equipped with a generator so that the refrigerators and water circulating pumps can be run by electricity.

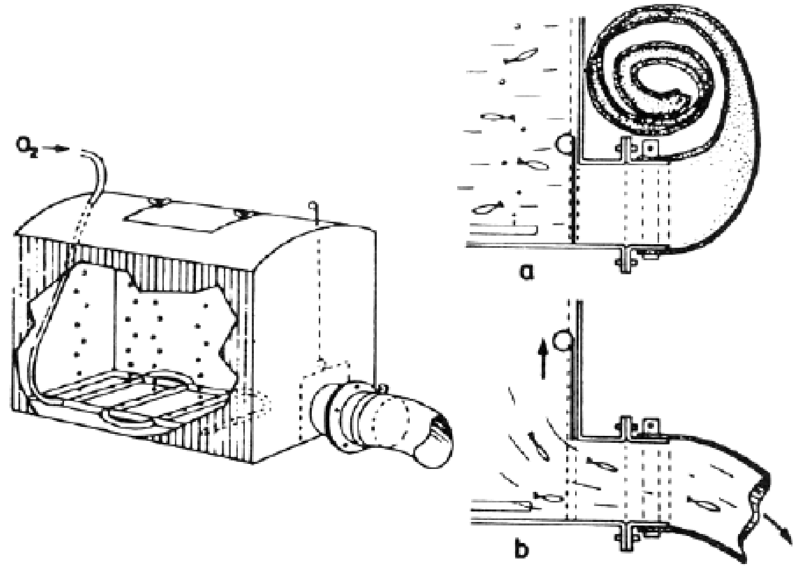


Figure 22 Transport tank with hopper (a) during transport; (b) unloading (Horváth, Tamás and Tölg, 1984)

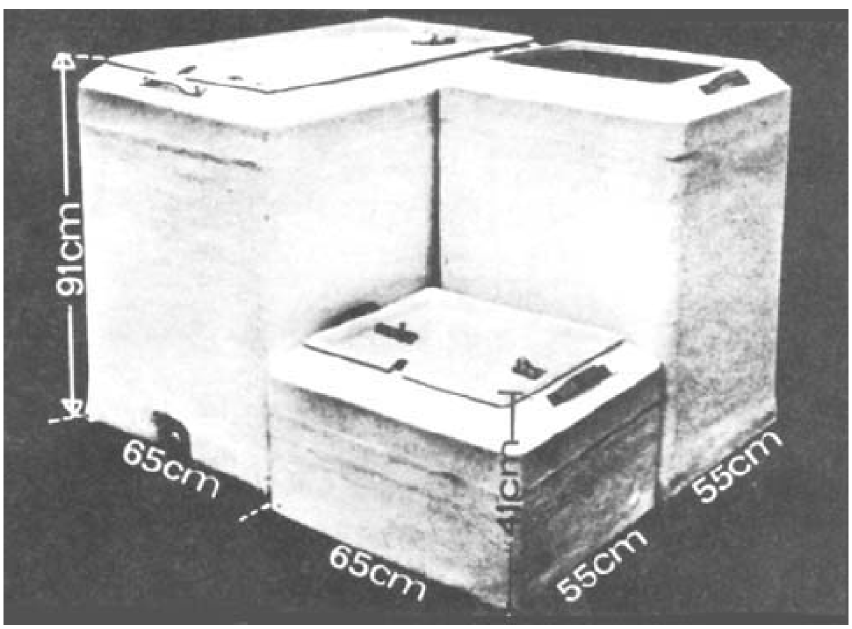


Figure 23 Transport tanks with 100, 300 and 600-litre volume (EWOS). Standard equipment: one lid with cutting out for a tube for oxygen. The latter two types are equipped with water drawing as well as fittings for mounting

The pumps and refrigerators are driven by separate gasoline engines on other models. The aeration system is generally designed with the water drawn from the bottom of the tank by pumps. It passes through a venturi to inject air into the water and is then sprayed back into the tank over refrigeration coils. The 1 800-litre tanks have small electric pumps at each end of the tank which operate from a heavy-duty truck battery. The water is picked up at the bottom of the tank and sprayed back. This type of tank holds the temperature very constant without refrigeration because the water does not pass through a venturi on the outside of the tank and warm air is drawn from the atmosphere into the water. Some tanks are also supplied with bubbles of oxygen through a carborundum stone from a bottle of compressed oxygen. The fish planting equipment, particularly the larger tank trucks, are complicated and expensive. There should be an operating manual with each piece of equipment.

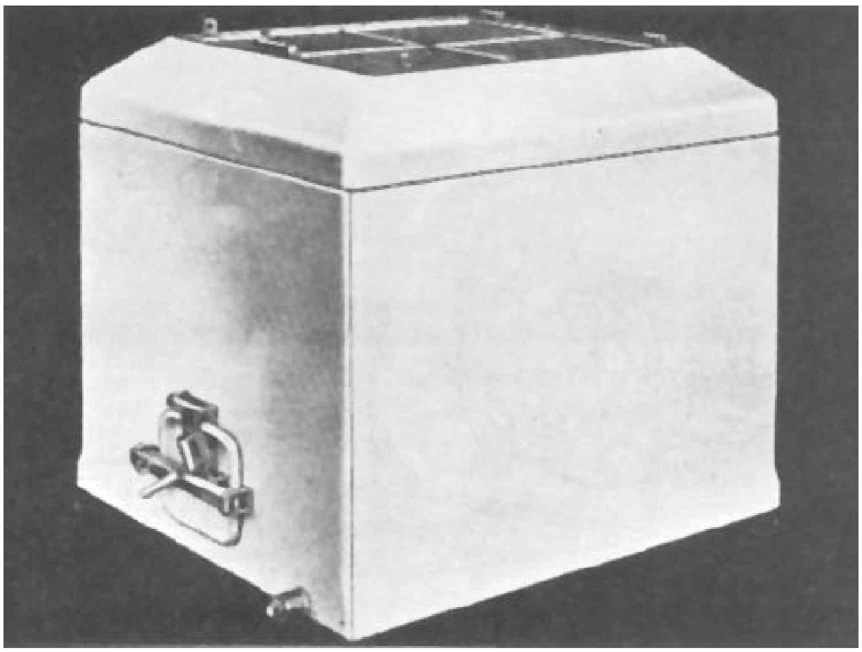


Figure 24 Transport tank of volume 900 litres, specially made for the transport of eel (EWOS). As a standard, the tank is equipped with a double bottom, under which an air hose can be installed

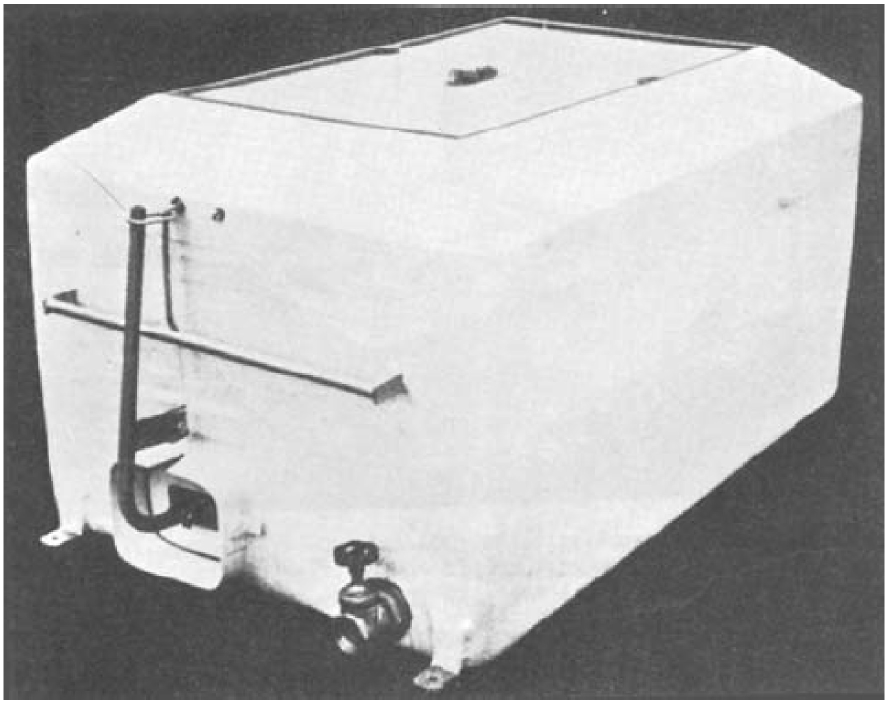


Figure 25 Transport tank (EWOS). Dimensions 150 × 100 × 85 cm, volume 1 200 litres. The capacity of the tank for short transports of 4–5 hours and with access to water below 10°C is 100–150 kg of fish in good condition. The tank is equipped with a tight-fitting lid. It has a 5 cm drain with a valve and can also be delivered with a protruding collar 20 × 25 cm

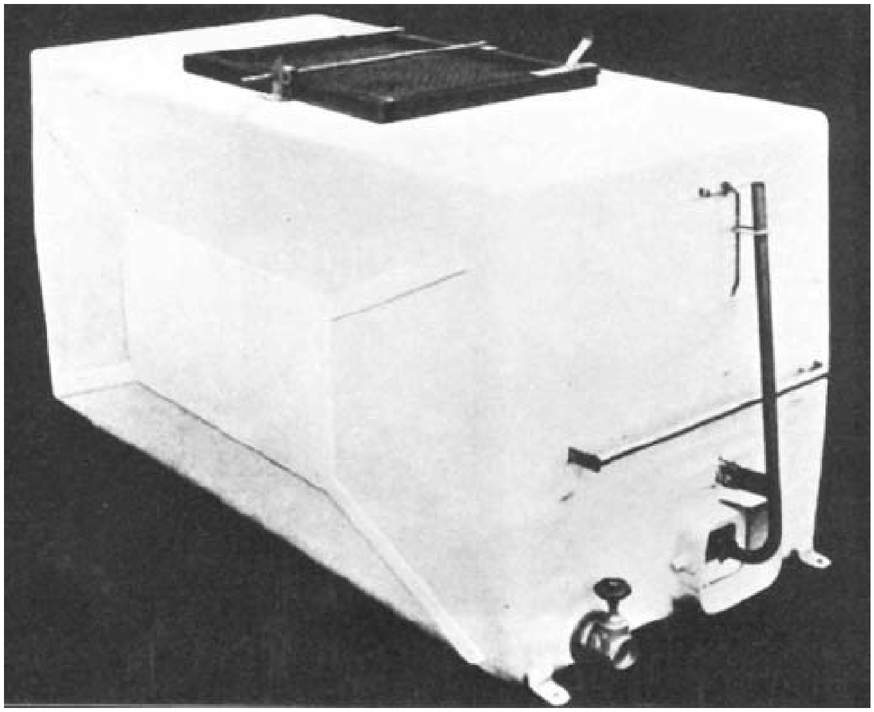


Figure 26 Transport tank (EWOS). Dimensions 200 × 100 × 100 cm, volume 2 000 litres. Tank is mainly used for short transports of live rainbow trout but can be used for all kinds of live fish. For rainbow trout it has a capacity of 200–300 kg during day-long transports and a water temperature not exceeding 18°C. As a standard, tank is delivered with a lockable, screened lid and 2 inches valve with inside screen for drainage. Extra equipment: protruding collar 20 × 25 cm or 30 × 40 cm for larger fish; double bottom (installed when air hoses are used); large opening with splash board; top with 2 lids; gutter

Another type of fish transport truck, described by Piper *et al.*, (1982), is presented in Fig. 39.

A small special vehicle for fish transport is shown in Fig. 40. It is a well-equipped system of a ¾-ton heavy-duty truck. The tank is constructed of stainless steel and is divided into two compartments. Quick-release gates and removal chutes permit rapid unloading of the fish. Agitators provide aeration, but compressed oxygen is available for emergencies.

Soviet special vehicles for fish transport are also differentiated as to capacity, the container volume being usually between 2 400 and 4 000 litres. Their detailed descriptions and operation conditions are given by Mackevich and Shiyanov (1984), Pavlov (1973), Kozlov *et al.*, (1977) and Dyagilev (1974). A typical diagram of such vehicles is shown in Fig. 41. The water in the tank is aerated by means of an own compressor; truck engine is used for supplying the air in some types of trucks, or water is oxygenated with gaseous oxygen from pressure bottles. In large-volume tanks partitions are installed to damp water movements during transport. Bigger trucks (volume above 4 000 litres) are also equipped with an aggregate for water cooling; a thermoregulator is used to control this device.

A special truck with a 13 000-litre tank (Barekyan *et al.*, 1975) is used in the USSR for fish shipment, mainly for transporting brood fish to longer distances (Fig. 42). The truck has a powerful ejector device for water aeration, keeping the orientation of the fish during transport. The transport tank is thermally insulated, the space for the fish has the dimensions of 4.2 × 1.4 × 1.6 m. The minimum flow rate of water through the tank for orientating the fish is 0.2 $m.s^{-1}$.

There are many other specialized fish transport trucks in the world; they include, for instance, fully equipped fish transporters in which the triple-compartment steel tank (2 227 litres) forms an integral part of the special body, mounted on a wheel-base chassis cab unit, for on-off road duties (Fig. 43), or transport vehicle equipped with liquid oxygen (Fig. 44).

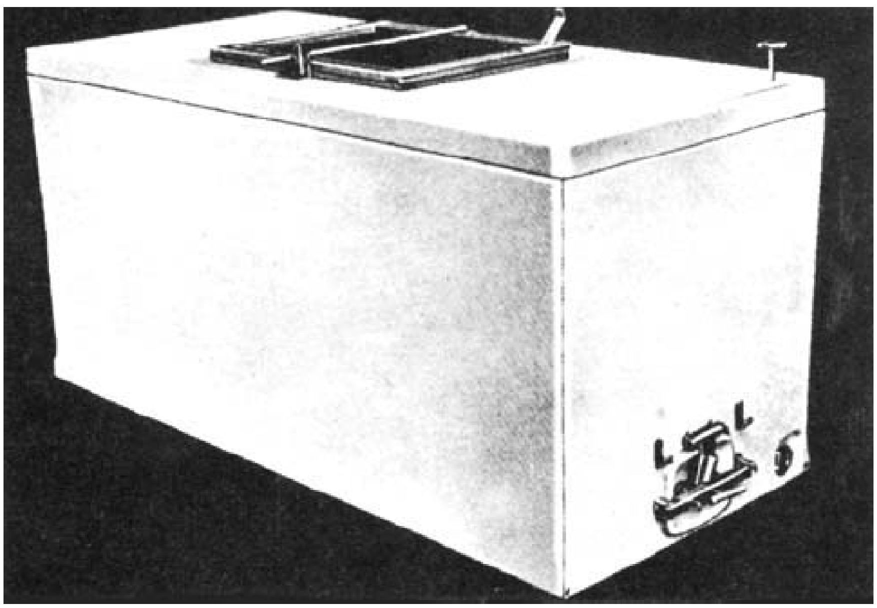


Figure 27 Transport tank (EWOS). Dimensions 236 × 108 × 112 cm, volume 2 400 litres. Tank is specially designed for long transports and is therefore built with double walls with a polyurethane foam insulation. For draining, the tank is fitted with a valve with an inside screen; the valve is operated with a knob on the top of the tank. As a standard it also has an outlet gate 20 × 25 cm. The capacity of this tank is about 300–400 kg of rainbow trout depending on the length of the transport, water temperature and water quality. For day-long transports of trout of a size 25–50 g, a load of 150–200 kg can be suitable, providing the water quality is good and the temperature not above 10°C

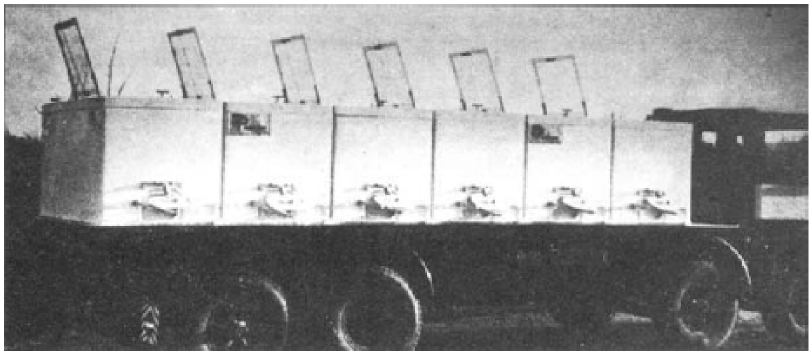


Figure 30 Transport tanks (POLOPLAST; Italy)

For the transport of salmonid fry, US fish farmers use large fish transport trucks (anonym, 1980) which have doubled the previous fish transport capacity (Fig. 45). The system is designed to eliminate the need for recirculating water pumps which increase water temperature and, accordingly, the need for refrigeration systems to control this heat build-up. Instead, it will employ air-lift pumps to recirculate the water using oxygen as the lifting or operating force. The water that is lifted will be injected into filter beds, placed above the main body of water in the tank holding the fish, and then spread throughout the tank so that velocities are minimized and zones of stagnation eliminated. The filter beds control various media to physically remove protein-containing materials; other waste products, such as carbon dioxide and ammonia, either chemically or by absorption. Primary control of the water quality plays an important role. All dissolved nitrogen is removed from the water so that oxygen saturation levels can be elevated by over 2.5 times. The pH is controlled to ensure efficient chemical removal of the carbon dioxide produced by the fish without increasing the ammonia content to toxic levels.

A 20-ton semi-trailer (Fig. 46) is in operation in Great Britain for transporting live fish fry and fingerlings, principally to transport elvers. A maximum of 12 million elvers weighing four tons can be carried on 18 insulated water tanks arranged in pairs down the length of the vehicle. There is a life-support system, which is powered by two diesel engines linked to three-phase alternators. The alternator supplies power to drive the aeration, refrigeration and water-circulation system. Only one diesel engine is required, but in the event of a power shutdown for any reason, the second will start within 30 seconds. The trailer was built for Bristol Channel Fisheries of Gloucester, England (Anon., 1980, 1982). This vehicle was also used to transport 400 000 fingerling eels from England to Hungary, a distance of 3 600 km in 3.5 days. A water temperature of 7°C was maintained throughout the journey by a refrigeration plant in the trailer, and oxygen levels were kept up by cooled compressed air distributed through ceramic diffusers in each tank. The same water was used from start to finish. Exchange of water means exposing the fish to different range of physical and chemical parameters, causing some degree of stress; more important is the possibility of introducing exotic pathogens into the consignment. The life-support systems are duplicated. During a sea crossing the transporter is connected to the ship's three-phase electrical supply.

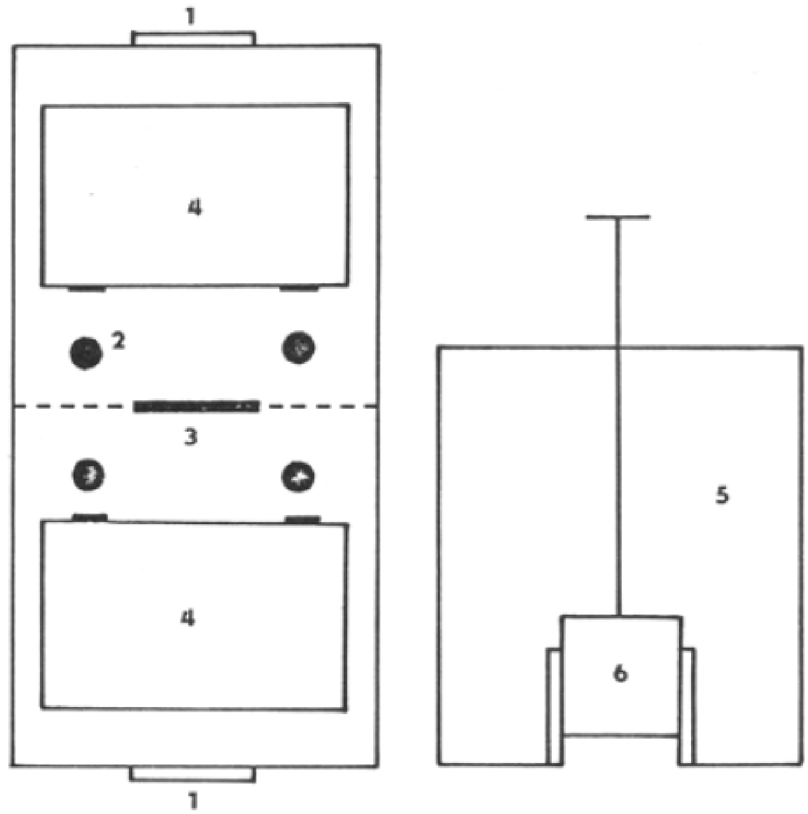


Figure 31 Diagram of a two-compartment tank (Okoniewski, 1975). 1 - drain opening, 2 - openings for aerators, 3 - separating gate, 4 - tank top, 5 - tank partition, 6 - separating gate

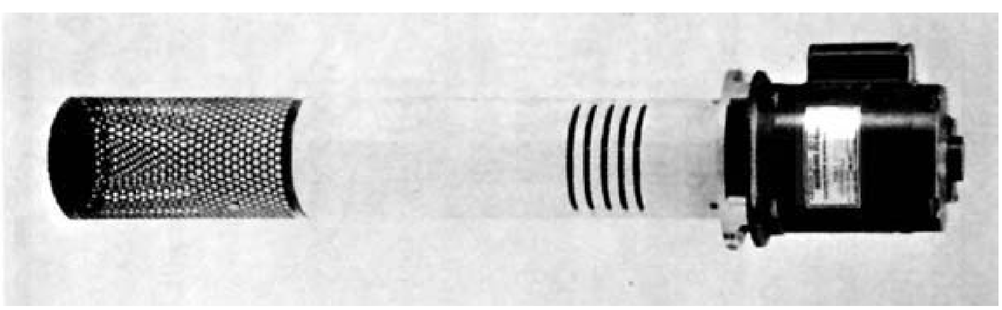


Figure 32 Aeration agitator. 1 - fan to cool the engine, 2 - electric motor, 3 - transmission shaft, 4 - agitator blades, 5 - protecting grid

4.3 Water Aeration/Oxygenation and Temperature

The system of water aeration or oxygenation still has to be evaluated in detail. Its effectiveness depends on a number of technical and economic conditions. Discussion on these problems has been published by Heiner (1982, 1983), Johnson (1979), Proske

(1982), Leis (1978) and others. Air and gaseous oxygen have become traditional ways of conditioning the transport water; nevertheless, the use of liquid oxygen is becoming a more accepted method in transport. Like compressed gaseous oxygen, there is an advantage in avoiding problems with mechanical failure. In addition, the equipment is lighter than for gaseous oxygen and the cost of oxygen is less. Liquified oxygen is packaged in a different container than gaseous oxygen but when it comes out of the container it is transformed into the gaseous state. The release is typically through perforated piping in the tank bottom. Air and oxygen are also used simultaneously for aeration to avoid the consequences of errors in oxygen supply during transport (phenomenon called "burning the fish" during transport which has not yet been fully explained). For this reason some advanced transport trucks such as, for instance, the new transporter produced by German HTT-Fischzuchttechnologie GmbH (Anon., 1984) are equipped with an integral air blower with no danger of "burning" the fish.

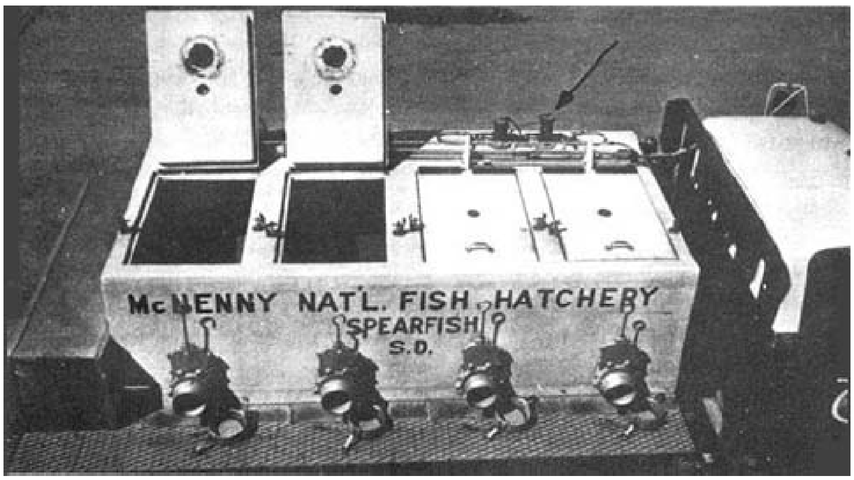


Figure 33 Fiberglass transport tank with four compartments, each with an electric aerator (arrow). Additional oxygen is provided through carbon rods or micropore tubing on the bottom of the tank (Piper *et al.*, 1982)

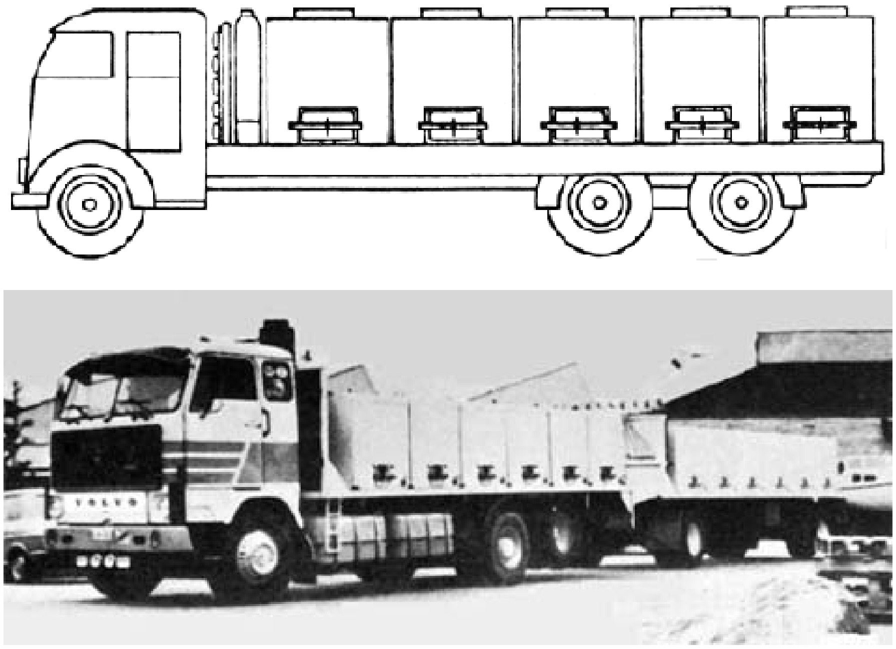


Figure 34 Installation of transport tanks on a truck. The transport capacity of the truck is about 8 000 litres; when the truck is combined with a trailer, the volume of the fish tanks is about 15 000 litres

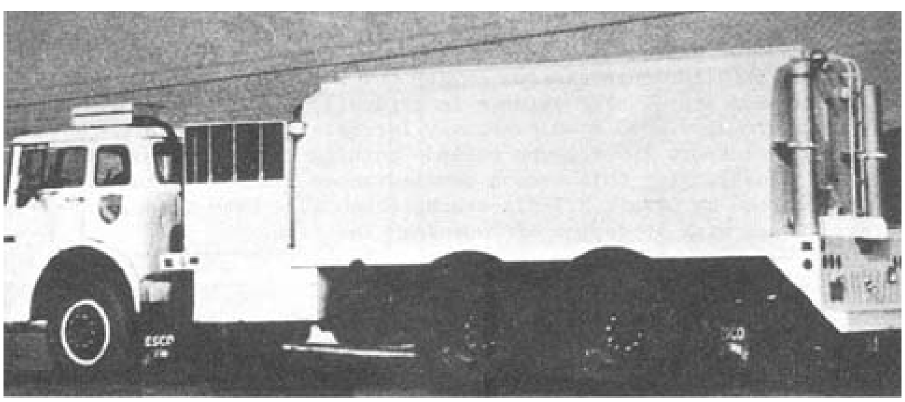


Figure 35 A 11 400-litre fish transport truck. The water pumps and refrigeration units are operated by electricity which is generated by a diesel-driven unit on the truck (Leitritz and Lewis, 1976)

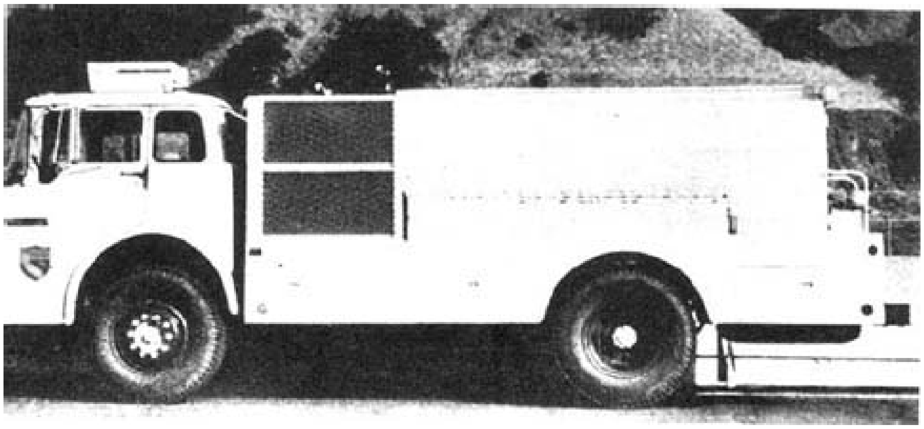


Figure 36 A 5 400-litre fish transport truck. The water pumps and refrigeration units are powered with gasoline engines (Leitritz and Lewis, 1976)

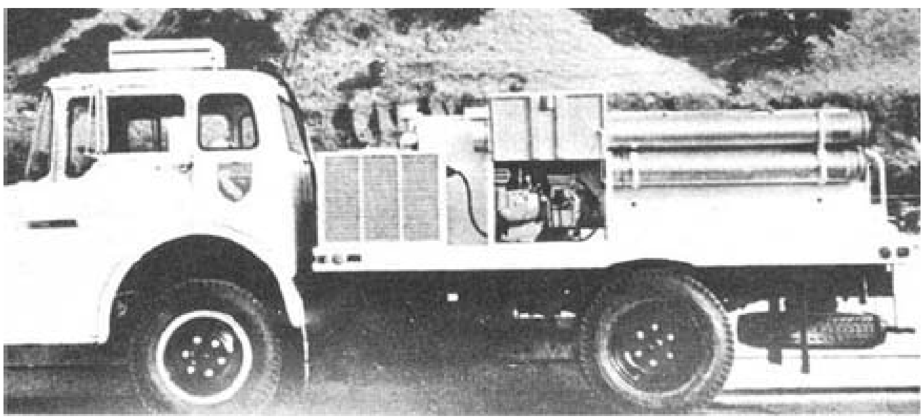


Figure 37 A 2 700-litre fish transport truck. Electric water pumps and refrigeration units are powered by a gasoline generator (Leitritz and Lewis, 1976)

Figure 38 A 1 800-litre fish planting tank is mounted on a flat-bed pickup truck. It is equipped with a small electric pump at each end of the tank which operates from a generator or a heavy-duty truck battery, and sprays the water to the middle of the tank. It holds the temperature very constant (Leitritz and Lewis, 1976)

Figure 39 Aluminium elliptical tank with refrigeration unit mounted at the front. Aeration is by gas-driven pumps and pure oxygen. Note air scoops (arrow) for CO_2 removal on front and rear of tanks (Piper *et al.*, 1982)

Besides the general principles presented in Chapter 2, it is suggested by practical experience that air or oxygen supply should be adjusted already before loading the fish, because later it is practically impossible to change the size of the bubbles. A short time after starting transport, 10–15 m after departure, it is recommended to stop and to check the behaviour of the fish in the tanks. In winter the transported fish are exposed to increased danger: a small amount of water frozen in the oxygen distribution piping or in the fittings may cause the failure of the whole system, however sophisticated it may be.

Water temperature is an important factor of fish transport. General-orientation data on the changes in water temperature in specialized fish transport trucks in dependence on transport time and ambient temperature, evaluated by Leis, Kruzhalina and Dyagilev (1984), are given in Table 19.

4.4 Fish Densities in Transport Units

Data on the possible densities of fish transported in open systems are scarce in literature. Though Leis (1978) described a calculation method for the oxygen requirement in fish transport, his methodology cannot be widely used in practice because the calculation formulae are very complicated. On the other hand, many authors state that fish consume only a small portion of the oxygen offered (10 percent at the maximum, as asserted by Proske, 1982), so that the calculations of oxygen requirement, based on the amount consumed by the fish, are not reliable. Like in the closed systems, it is also true that the optimum fish densities in transport containers are influenced by a number of factors which should be learned and evaluated by practical experience rather than by theoretical calculation. Most of the authors also recommend to take into account the possibility of delay during the journey which may be up to 24 hours in longer transports.

Figure 40 Small fish transport truck equipped with aerators and oxygen bottle for emergency (Dupree and Huner, 1984)

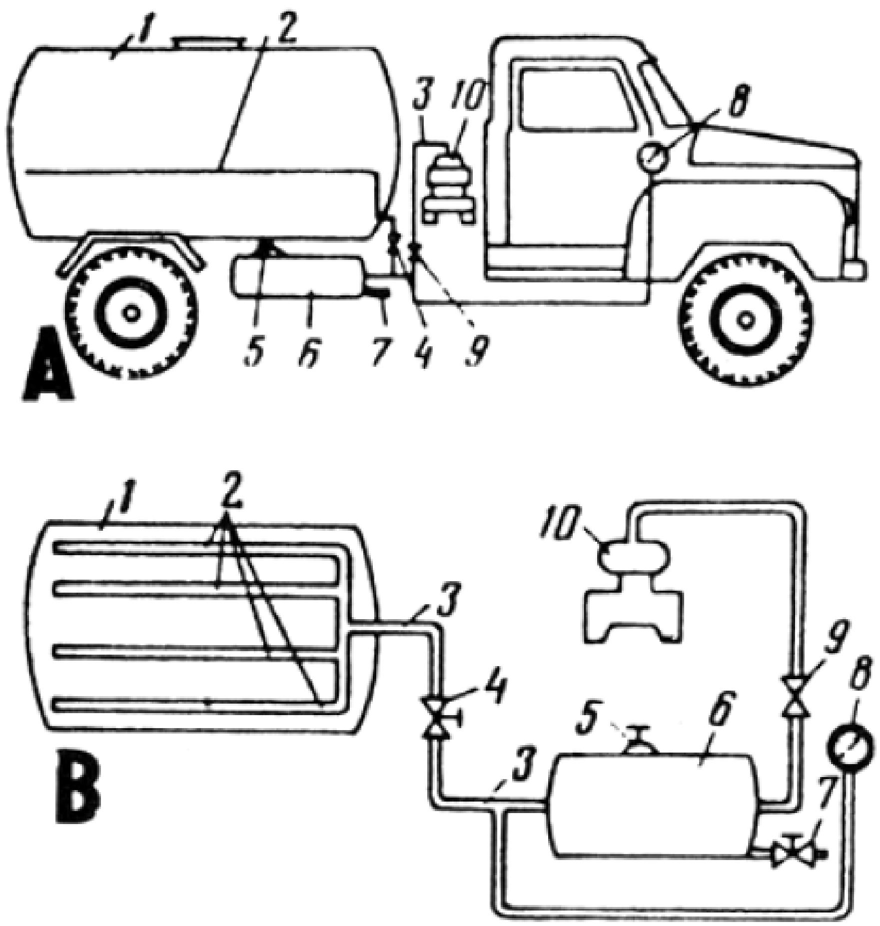


Figure 41 A transport truck (A) equipped with an aeration system (B) (Mackevich and Shiyanov, 1984) 1 - tank, 2 - perforated air hoses, 3 - air supply, 4 - air supply regulator, 5 - safety valve, 6 - pressure tank for air, 7 - valve for discharging the condensate, 8 - pressure gauge, 9 - check valve, 10 – compressor

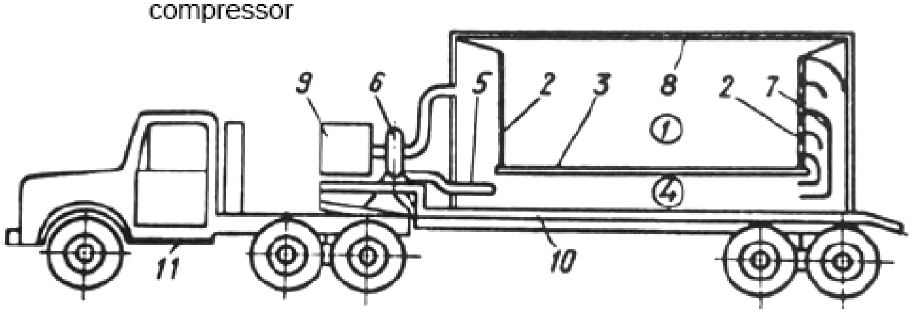


Figure 42 Soviet 13 000-litre fish transport truck (Barekyan *et al.*, 1975) 1 - space for the fish transported, 2 - grate wall, 3 - bottom of the fish space, 4 - space for water-air mixing, 5 - ejector, 6 - centrifugal pump, 7 - deflectors, 8 - air-tight sealing of the tank, 9 - engine, 10 - trailer, 11 - towing vehicle

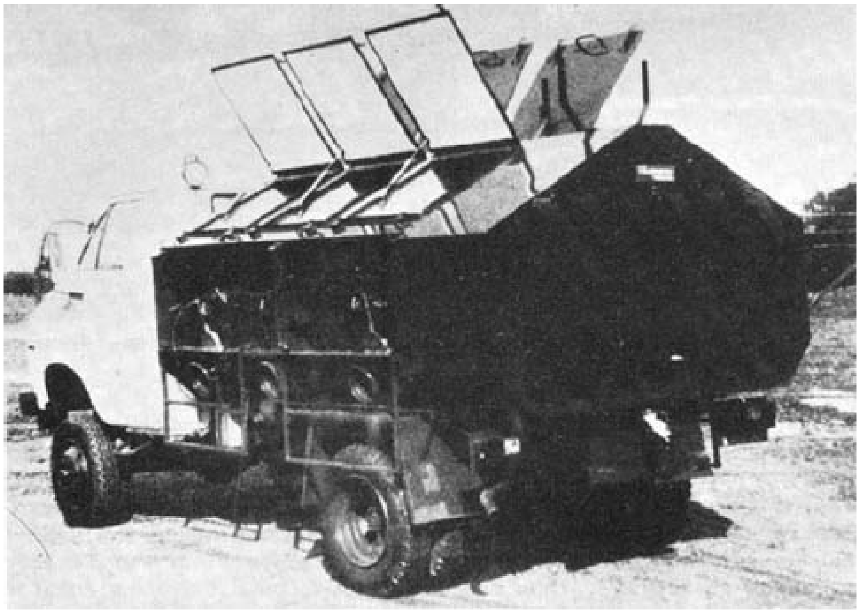


Figure 43 A 2 227-litre fish transporter (BUCKINCHAM VEHICLES Ltd.)

Figure 44 A fish transport vehicle equipped with liquid oxygen supply, oxygen flow valves, agitators, side ramps, and lighting for night hauling (Johnson, 1979)

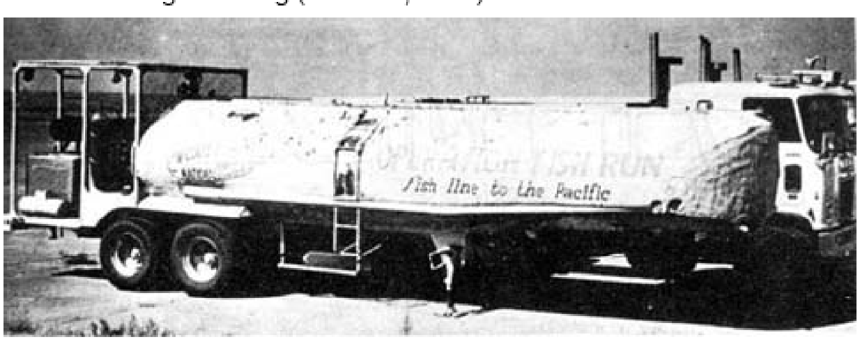


Figure 45 Fish truck, used in the USA, equipped for water quality control during transport

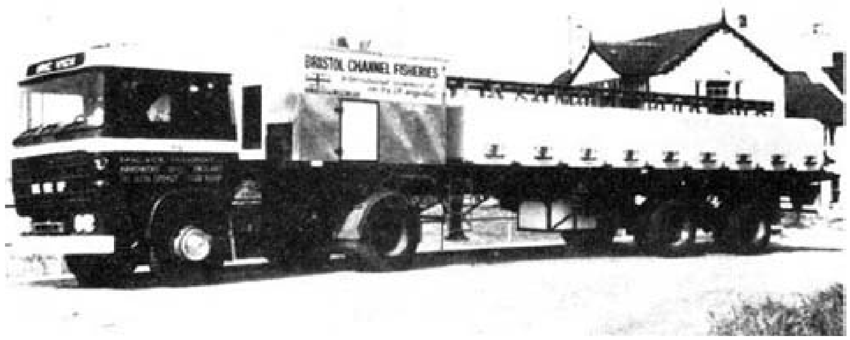


Figure 46 Semi-trailer used by Bristol Channel Fisheries for transporting live fish

Some guide figures concerning fish transport are given by Horváth, Tamás and Tölg (1984) in Table 20, Proske (1982) in Table 21, and Dupree and Huner (1984) in Table 22.

Exact standards of the densities of transported fish are suggested by Uryn (1971) for the early fry of *Coregonus lavaretus* and *Coregonus albula*. Though belonging to the same family, these two species have a markedly different oxygen demand during transport: fry of *C. Lavaretus* consume 2.4 times more oxygen, on an average, than the fry of *C. albula*. The calculation is based on the lethal threshold of oxygen (Table 23) and on the intensity of oxygen utilization (Table 24) in each of the two species. The calculation of the transport density standard for the fry can be demonstrated by the following example (the calculation applies to *C. lavaretus*): planned transport time is 2 h; water at the temperature of 6°C contains 7.5 mg. 1^{-1} oxygen; at this temperature, the lethal oxygen threshold is 1.50 mg.1^{-1}, and the intensity of oxygen utilization is 3 mg. per 1 000 fry per hour (Tables 23 and 24). Hence, one litre of water contains the following amount of oxygen available to the fry: 7.5-1.5 mg. 1^{-1} = 6 mg. 1^{-1}. This amount per litre, converted per one hour of transport time, can be utilized by the following amount of fry:

For	1 000 fry, one needs	3 mg. h^{-1} oxygen
For	x fry, one has	6 mg. h^{-1} oxygen, therefore
	$\underline{x = 2\,000 \text{ fry} \cdot 1^{-1} \cdot h^{-1}}$	

Transport time is planned to be 2 h; hence, the amount of fry should be divided by two: 2 000 fry : 2 = 1 000 fry ◦ 1^{-1}.

4.5 Transport of Pike-Perch

The transport of pike-perch is of a somewhat specialized nature; pike-perch is a species extraordinarily sensitive to any handling. It holds generally that the smaller the fry of pike-perch the better the transport. Vollmann-Schipper (1975) recommends a special container for the transport of pike-perch fry (Fig. 47), equipped with a water-tight cover and aeration; Horváth, Tamás and Tölg (1984), in turn, recommend plastic tanks 80–150 litres (Fig. 48) or 800–1 000 litres in size.

Table 19

The changes in water temperature in specialized trucks having no cooling equipment

Initial water Temperature (°C)	Duration of transport (in h) 10	20	30	40	50
	at ambient air temperature + 5°C				
10	10	9	8	7	7
15	13	11	9	8	7
20	16	14	12	10	9
25	20	16	14	12	10
	at ambient air temperature + 15°C				
5	7	9	11	12	13
10	11	12	13	13	14
20	19	18	17	17	16
25	23	21	19	18	17
	at ambient air temperature + 25°C				
5	10	14	16	18	20
10	14	16	18	20	21
15	17	19	21	22	23
20	21	22	23	23	24
	at ambient air temperature - 5°C				
5	3	1	-	-	-
10	6	4	2	-	-
15	10	6	4	2	-
20	14	9	6	4	2

Table 20

Guide numbers for 5–20 h transports of fish with average body weight of 1 000 g with a proper oxygen supply

Fish species	Amount of fish (kg) in 1 000 liter water at							
	0–5	5–8	8–10	10–15	15–20	20–25	25–28	30°C
Common carp and tench	700	600	450	400	350	280	220	180
Grass carp	750	650	500	450	400	310	250	200
Silver carp	300	250	200	150	100	80	no suggestion	
Bighead carp	700	650	500	450	400	300	220	180
Sheatfish	800	700	600	500	400	320	250	200
Pike-perch	250	200	150	120	100	80	no suggestion	

Notes:

1. The amount of water for transport can be calculated by substracting the volume of fish to be transported (with 1 kg/1 litre index) from the total volume of the tank
2. Data at a temperature value above 15°C refer to fasted fish
3. Transport guide numbers of fish with 1 000–1 700 g body weight can be increased by 10–15% Numbers given can be decreased in the following way:
   20–30% if the body weight is about 500–1 000 g
   30–50% if the body weight is about 200–500 g
   50–60% if the body weight is about 100–200 g
   60–80% if the body weight is under 100 g

Table 21

Fish weight in kg per 100 litres of water when the transport lasts 4–8 h

Temperature (°C)	Carp				Rainbow trout			
	Advanced fry	One-year-old fish	Two-year-old fish	Marketable fish	Advanced fry (4 cm)	Young fish (8 cm)	Young fish (12 cm)	Marketable fish (250 g)
5	-	30	50	70	15	25	30	35
10	-	25	35	50	12	20	25	30
15	10	20	25	35	-	10	15	20

Table 22

Capacity fish load in kg per 100 litres of water for transport by the tank method with agitators or blower system in hard water at 18°C

Type of fish and average length (in cm)	Duration of transport (in h) 1	6	12	24
Fingerlings				
5	20	15	10	10
20	30	30	20	15
Adult fish				
36	40	40	30	20

Table 23

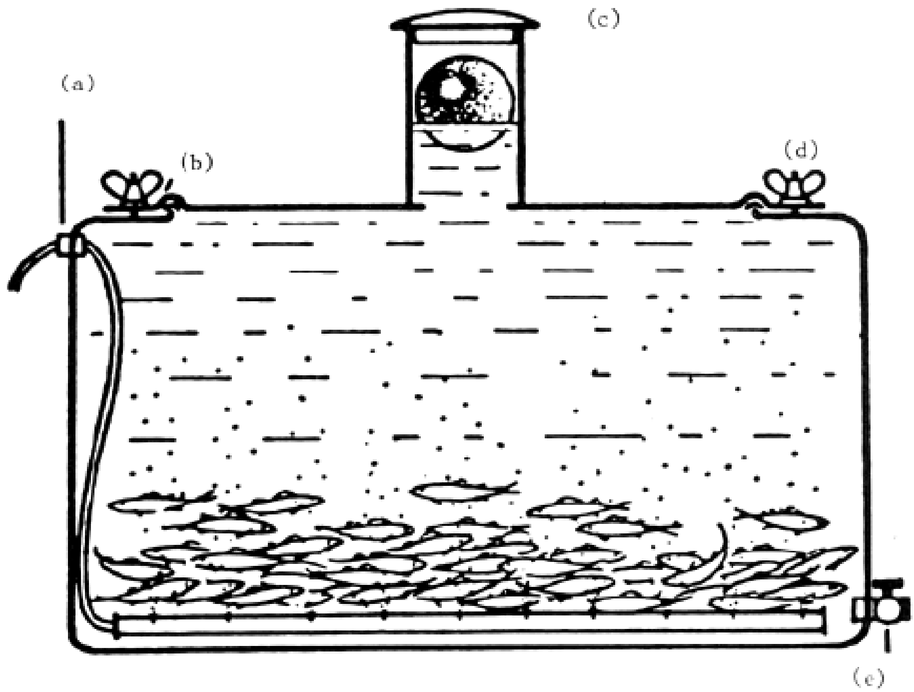
Average lethal oxygen threshold for the early fry of *Coregonus*spp. in function of water temperature (in mg. 1^{-1})

	Temperature (in °C) 4	6	8	10	12	14
C. lavaretus	1.3	1.5	1.5	1.7	1.7	1.8
C. albula	1.3	1.4	1.5	1.6	1.7	1.8

Table 24

Average oxygen consumption by the fry of *Coregonus*spp. in function of the water temperature, in milligrams per 1 000 fry per 1 h

	Temperature (in °C) 4	6	8	10	12	14
C. lavaretus	2.7	3.0	3.8	4.0	4.8	4.8
C. albula	1.1	1.4	1.6	1.6	1.9	2.1



(a) Aeration device; (b) Rubber joint; (c) Removable cover; (d) Tightening screw; (e) Outlet valve

Figure 47 Specialized tank for pike-perch transport (Vollmann-Schipper, 1975)

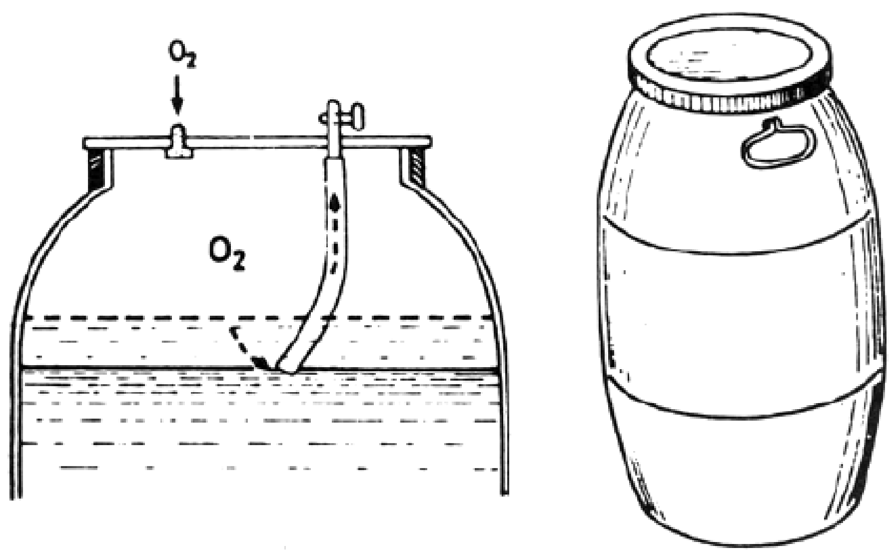


Figure 48 Plastic tank for pike-perch transport (Horváth, Tamás and Tölg, 1984)

Pike-perch get unjured - especially in the eyes - from the movement of water or by bumping into each other. This can be prevented by filling the tank completely with water and installing a valve for gas exchange (Fig. 48). In a hermetically closed tank, oxygen supply stops due to overpressure and the fish die.

Guide data on the transport of pike-perch in tanks are presented in Table 25 according to Horváth, Tamás and Tölg, 1984.

Table 25

Guide numbers for pike-perch transport

Age group Total length	Duration of transport (in h)	Closed water tank of 120 lit. (100 lit. water + 20 lit. O_2)				Closed water tank of 1 200 lit. (1 000 lit. water + 200 lit. O_2)			
		Temperature (in °C)							
		10	15	20	25	10	15	20	25
Early fry of 6–7 mm (thousand)	2	280	180	90	-	2 000	1 000	500	-
	5	200	150	60	-	1 500	800	400	-
	10	150	90	40	-	1 200	600	300	-
	15	120	60	25	-	1 000	400	200	-
Advanced fry of 3–5 cm (thousand)	2	15	10	6	2.5	180	120	80	25
	5	12	8	4	1.6	130	100	50	16
	10	8	5	2.2	1.2	90	60	25	10
	15	5	3	1.5	0.7	50	30	18	7
One summer fingerlings	2	1 000	800	600	-	10 000	8 000	5 000	-
	5	800	600	400	0	8 000	6 000	4 000	-
	10	600	500	300	-	6 000	4 000	2 500	-
	15	500	400	200	-	5 000	3 000	1 500	-
Two-summer old fish	2	180	100	60	0	1 800	1 200	700	-
	5	140	70	40	-	1 500	800	500	-
	10	100	50	25	-	1 100	600	300	-
	15	50	30	15	-	600	400	200	-

Nevertheless, juveniles of pike-perch can also be transported with success in standard tank. Kavalec (1973) commented on the transport of pike-perch fry from Czechoslovakia to Sweden over 1 200 km. The shipment lasted 41–55 h, depending on the place of release in Sweden. The temperature of the water was 7°C and the oxygen content 7 mg. 1^{-1}; air compressors were used to aerate the water. During transport, the oxygen level decreased even to 4 mg. One transport tank containing 2 000 litres of water accommodated 5 000 pike-perch fry 11–14 cm in length; 1 000-litre containers were carried on a trailer pulled by the truck and were stocked with 5 000 9–10 cm pike-perch fry. The fish reached their destination in very good condition.

4.6 Railway Fish Transport

Shipment by special tank wagons should be mentioned if complete information of fish transport is to be provided. However, this system of fish transport is being abandoned. At present, when highly advanced road transport is available, the disadvantages of railway fish transport have become obvious (usually two transloadings of the fish, a longer transport time); they highly prevail over the possible advantage from the point of view of transport economy.

The diagram of the technical design of the wagon is shown in Fig. 49 and a detail of the aeration system is shown in Fig. 50. The wagon is designed for the transport of 8–12 tons of fish, usually market cyprinids. The amount of fish transported depends on temperature because the wagons usually have no cooling system. In the variant described by Vollmann-Schipper (1975) the dimensions of the tank are 3 × 3 × 1.4 m. Oxygen cylinders are kept as a reserve to replace, in case of failure, the air compressor used during the journey. When the transport time is longer, water is completely replaced in the tank in the marshalling yards. The mad deposited on the bottom is drained from the tanks during the trip. Some experience with the railway transport of different fishes is described by Soviet authors (Smorodinskaya and Khasman, 1973; Orlov, 1975; Kruzhalina, Averina and Vol'nova, 1970; Shevchenko, 1978; Demchenko, 1970).

5. CHEMICAL METHODS FOR WATER AND FISH TREATMENT DURING TRANSPORT

The chemical methods of treating the transport medium, aimed at increasing the capacity volume of the transport units and preventing physiological and health damage to the fish, constitute an integral part of the complex problem of fish transport. They include the use of anaesthetics, water-hardening and oxygen-producing chemicals, bacteriostatics, buffering and antifoam chemicals.

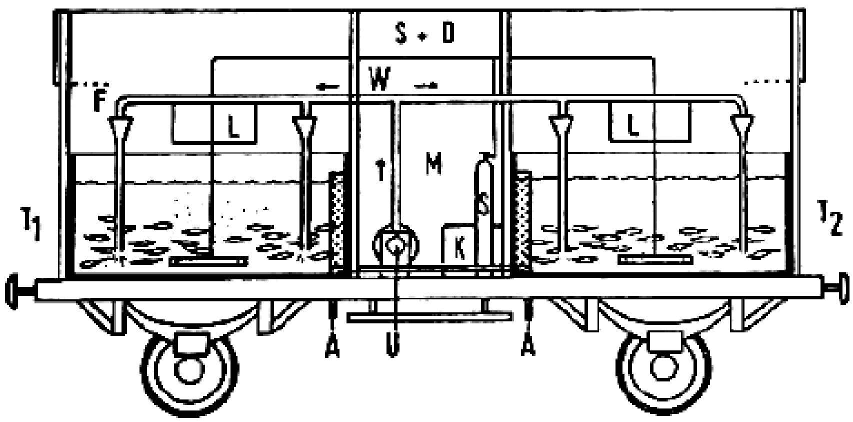
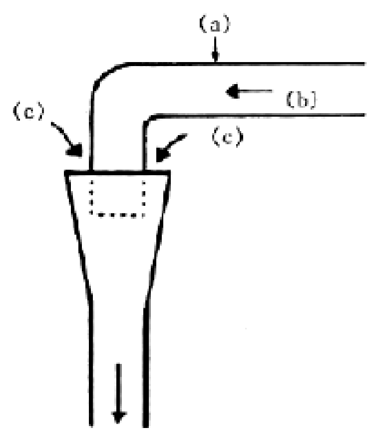


Figure 49 A fish transport tank wagon (Vollmann-Schipper, 1975) M - technical space and attendant's booth, U - pump and air compressor, T - Transport tanks 1 and 2, S - oxygen cylinders, A -tank drain, F - water aeration (for details see Fig. 50), L - loading space, W - circulating water distribution system, S + D - oxygen or compressed-air distribution system



(a) Water inlet pipe;
(b) Water; (c) Air

Figure 50 Water aeration in the tank wagon (Vollmann-Schipper, 1975)

5.1 Use of Fish Tranquilizers

During transport, sedation of the fish is desirable, since oxygen consumption and CO_2 and NH_3 production are all decreased. However, deep sedation is undesirable because the fish may fall to the bottom, pile up and smother. If pumps are used, the fish may be pulled into the screen, the air may move the deeply sedated fish about and cause a loss of scales. It is best to sedate the fish in the holding facility for 30 min before loading and then to continue exposure to a lower concentration of sedative during transport. The use of anaesthetics should not be relied on for increased load carrying capacity. Other methods are safer and dependable. The use of anaesthetics on food fish that will be consumed soon after exposure is not legal. Consideration should always be given to the legal status of a chemical and possible consequences to the consumer.

Anaesthesia usually applies only to transported brood fish. In practice, the fish are first tranquilized with the normal dose and put into the transport tank, where original concentration is diluted by 50 percent by adding the same amount of fresh water. The brood fish will remain tranquillized well in that diluted solution (Woynarowich and Horváth, 1980). It is advisable to find out the right dose for the fish in question through experimentation. Sensitivity resistance and endurance vary from fish to fish. Even the near related species may differ very much in this respect.

It is not recommended to use anaesthetics on small fish transported on small distances, since in such conditions the space factor has a greater influence on the health of the fish than the accumulation of metabolic products (Shevchenko, 1978).

As Woynarowich and Horváth (1980) assert, fish transport in cold water of 5–10°C is the simplest and best method of anaesthesia; however, this cannot always be done. This view is also supported by Strebkova (1971) who found no differences between the anaesthetized fish and the untreated control fish transported at a temperature of 11–13°C. Horváth, Tamás and Tölg (1984) recommend to anaesthetize the fish for transport only in cases of temperatures above 15°C.

Among the broad spectrum of anaesthetics, tricaine methanesulfonate (MS-222) and quinaldine appear to be used most frequently.

MS-222 is a very mild tranquilizer and fish easily recover from its effects even after a long stupor. Horváth, Tamás and Tölg (1984) recommend to apply MS-222 to water at the rate of 20 $mg.1^{-1}$ for carp and grass carp, 10 $mg.1^{-1}$ for silver carp, and 35 $mg.1^{-1}$ for bighead carp or sheatfish. At these concentrations the fish can still hold their natural position but their respiration and motility are significantly decreased. When applying this anaesthetic, the mass of transported fish in a unit volume can be increased by 50–150 percent, but it is best to test it before application. About the same concentrations of MS-222 are also recommended by Woynarowich and Horváth (1980): the brood fish are first put in a full-strength solution, i.e., 5 g MS-222 in 100 litres of water. After 15–20 min when the fish are fully tranquilized, the solution is diluted by adding water to the concentrations commented on by Horváth, Tamás and Tölg (1984). The applicability of concentrations up to 50 $mg.1^{-1}$ to carp was verified by Rzanicanin and Balcer (1973, 1974) who found that MS-222 was desorbed within a short time: at the concentration of 50 $mg.1^{-1}$, MS-222 concentration in fish muscle was as low as 2 $mg.kg^{-1}$ after 15 h and no traces of the chemical were detected in muscle after 39 h. The MS-222 preparation was also used by Powell (1970) who applied it at the concentration of 7 mg, 1^{-1} to transported striped bass, and the results were good. Dupree and Huner (1984) recommend to use MS-222 at concentrations from 20 to 200 $mg.1^{-1}$ (whithout indicating the fish species), and claim that the preparation must be buffered between pH 7 and 8. The majority of authors believe that MS-222 has excellent anaesthetic properties, but - on the other hand - proves to be relatively expensive for everyday use.

Quinaldine (2–4 methylchinolin) is a toxic liquid and must, therefore, be handled with care. The fish are usually treated with it when they are held in a large volume of water, such as a large tank. Woynarowich and Horváth (1980) assert the effective concentration of 25 mg.1^{-1}, Dupree and Huner (1984) 15–30 mg.1^{-1}, nothing that quinaldine appears to be the most practical for warm-water fishes, although it may be damaging to trout and some other species.

Apart from these two tranquilizers, other drugs are to be used. Phenoxyethanol is another chemical that has recently come into use as a fish tranquilizer. It is milder and less effective than MS-222, but it is far cheaper; 30–40 cm^3 of phenoxy-ethanol are mixed with 100 litres of water for the treatment (Woynarowich and Horváth, 1980). As to other chemicals, Dupree and Huner (1984) describe the use of tertiary amyl-alcohol at 1.2 to 10.5 ml.1^{-1}, methyl pentynol at 0.4 to 2.6 ml.1^{-1}, and sodium bicarbonate at 0.5 g.1^{-1}.

Fereira, Schoonbee and Smit (1984) recommend to transport *Oreochromis mossambicus* treated with benzocaine-hydrochloride at a concentration of 25 mg.1^{-1}. A slow-reacting, long-lasting tranquilizing effect on trout is produced also by means of sodium amytal, one of the many hypnotic barbiturates available. The effectiveness of the drug is, to some extent, regulated by temperature. According to Leitritz and Lewis (1976), it appears to decrease when temperature rises above 12°C, the most effective range being from 8 to 12°C at a concentration of 7 mg.1^{-1}. Successful use of sodium amytal in combination with barbital preparations is also commented on by Strebkova (1971). Carbonic acid may also be used for tanquilizing fish. Dupree and Huner (1984) recommend the concentration of 0.1–0.4 mg.1^{-1}, Mishra, Kumar and Mishra (1983) transported fry (0.8 g) of *Labeo rohita* under the concentration of 0.5 ml.1^{-1} of carbonic acid. The product called Combelen (Bayer) was found to be effective in the transport of trout; this chemical is a neuroleptic which does not induce direct narcosis, but markedly reduces the effects of stress on the fish during transport (Studnicka *et al.*, 1982); for trout at a weight of 250–300 g kept in 5°C water, a Combelen concentration of 0.2 ml.$^{-1}$ was found to be effective.

5.2 Application of Sodium Chloride and Calcium Chloride

Handling stress and delayed mortality of fish can be decreased by the addition of sodium cloride (NaCl) and calcium chloride ($CaCl_2$) to the transport water. The sodium ion tends to "harden" the fish and reduce slime formation, and the calcium ion suppresses osmoregulatory and metabolic disfunction. Calcium chloride may not be needed in hard water already containing high concentrations of calcium. Dupree and Huner (1984) recommended the addition of 0.1 to 0.3 percent salt and 50 mg.1^{-1} calcium chloride. Some of the fishes that tolerate wide ranges of salt in the water, such as striped bass, tilapias, carp, can benefit from as much as 0.5 percent salt. Addition of 0.2 percent salt is recommended also by Johnson (1979). Different salt concentrations in dependance on water temperature should be used according to Hatting (1975): for water temperatures of 25–26°C he recommends the concentration of 0.7%, for medium temperatures 0.5% and for low temperatures 0.3%. Powell (1970) even used a salt concentration of 1% with a good result when transporting the fry of striped bass *Roccus saxatilis*. On the other hand, Carmichael (1984), though admitting that salt affords some measure of protection of the fish during transport, asserts that its function should not be over-estimated. Amend *et al.*, (1982) and Pecha, Berka and Kouril (1983) clearly state that no favourable influence of salt addition was demonstrated during fish transport.

5.3 Chemicals as Oxygen Sources

There are contradictory views concerning the use of chemicals as oxygen sources during fish transport. Huilgol and Patil (1975) tested the use of hydrogen peroxide on transported carp fry and found that one drop (1 ml = 20 drops) of hydrogen peroxide (6 percent concentration), applied to 1 litre of water, increased the oxygen content by 1.5 $mg.1^{-1}$ when the temperature was 24°C. CO_2 content and water pH were not influenced by the addition of hydrogen peroxide. Dissolved oxygen was measured by the Winkler method. Astapovich (1974) and Hartman (1976) tested peroxodisulphates for the same purposes; they also obtained a positive result of the enrichment of water with oxygen when measuring its content by the Winkler method. A revision of these results was performed in a detailed study by Máchová (1984) who demonstrated that peroxodisulphates $K_2S_2O_8$, $Na_2S_2O_8$, $(NH_4)_2S_2O_8$, in fact, release no oxygen into water and their use in fish transport is entirely useless. The Winkler's method of measurement in the presence of oxidants gives unreliable results; measurements should rather be performed with an oximeter.

5.4 Bacteriostatic Chemicals

Antibacterials are also used to check the development of bacteria in transport units. Among the wide spectrum of bacteriostatic drugs, the following are used most frequently: nitrofurazone (furacin) at 10 $mg.1^{-1}$, acriflavin at 1 to 2 $mg.1^{-1}$, oxytetracycline (terramycin) at 20 $mg.1^{-1}$ Combiotic at 15 $mg.1^{-1}$ (Dupree and Huner, 1984) and neomycin sulphate at 20 $mg.1^{-1}$ (Amend *et al.*, 1982). Antibacterials may strengthen the resistance of fish, but they are probably of little value as bacterial checks in transport tanks. Rare exception would be in the case where a superficial infection of an antibacterial-susceptible bacterium was in progress.

5.5 Buffers

Among other chemical additives, buffers such as "tris-buffer" (tris-hydroxylmethyl-amino methane) are helpful in controlling pH at a favourable value of 7 to 8. The accumulation of carbon dioxide in bag transport allows for a decrease in pH, because carbon dioxide is an acid. Since 2.2 to 4.4 $g.1^{-1}$ (Johnson, 1979; Amend *et al.*, 1982) or 1.1 to 2.2 $g.1^{-1}$ (Dupree and Hunter, 1984) of tris-buffer are required to control pH in bags with only moderate loads, the use of tris-buffer in tank transport usually is impractical because of cost.

5.6 Ammonia Control

To control ammonia concentration in the transport bags when the transport is expected to be long, it is recommended to use clinoptilolite, a zeolite mineral. Amend *et al.*, (1982) tested with success the dose of 14 g of clinoptilolite per litre, Bower and Turner (1982) tested the doses of 10–40 $g.1^{-1}$; the concentration of non-ionized ammonia nitrogen never exceeded 0.017 $mg.1^{-1}$ in bags containing even the lowest dose of clinoptilolite, whereas concentrations as high as 0.074 $mg.1^{-1}$ were recorded in the control bags left without clinoptilolite.

5.7 Antifoam Chemicals

The formation of foam and scum, especially when drugs are used in transporting fish or on water which is heavily laden with organic material (secretions and excretions, such as mucus and excrements) often becomes quite bothersome. The foam interferes with oxygen exposure at the water surface and also makes it difficult to observe the fish being carried. Water with NaCl foams less than water without NaCl, but NaCl may interfere slightly with the effectiveness of anti-foam chemicals. In some cases, a 10% solution of Dow Corning Antifoam AF Emulsion is used at the rate of 0.05 ml.1^{-1} of water (Leitritz and Lewis, 1976; Dupree and Huner, 1984). The advantages of using anti-foam chemicals are not so great, but their use does keep the water more clear so that the fish can be observed better.

6. CONCLUSION

Fish transport is a vast area comprising the problems of purely technical design on the one hand, and the chemistry of water, biological reactions of fish and the like, on the other. The above survey could only briefly mention and evaluate the relevant literature on these problems. In view of its purpose, the paper was designed not only as an analytico-synthetic survey of pertinent literature but, at the same time, as a practical manual to be used for seeking at least partial answers to practical questions concerning fish transport.

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EIFAC/T27	Water quality criteria for European freshwater fish. Report on copper and freshwater fish (1976)
CECPI/T27	Critères de qualité des eaux pour les poissons d'eau douce européens. Rapport sur le cuivre et les poissons d'eau douce (1976)
EIFAC/T28	Joint ICES/EIFAC Symposium on eel research and management (Anguilla spp.). Report (1976)
CECPI/T28	Symposium conjoint CIEM/CECPI sur la recherche et l'exploitation des anguilles (Anguilla spp.). Rapport (1976)
EIFAC/T29	Water quality criteria for European freshwater fish. Report on the effect of zinc and copper pollution on the salmonid fisheries in a river and lake system in central Norway (1977)
CECPI/T29	Critères de qualité des eaux pour les poissons d'eau douce européens. Rapport sur l'effet de la pollution par le zinc et le cuivre sur les pêcheries de salmonidés dans un système fluvio-lacustre du centre de la Norvège (1977)
EIFAC/T30	Water quality criteria for European freshwater fish. Report on cadmium and freshwater fish (1977)
CECPI/T30	Critères de qualité des eaux pour les poissons d'eau douce européens. Rapport sur le cadmium et les poissons d'eau douce (1977)
EIFAC/T31	Report of the Symposium on Finfish Nutrition and Feed Technology (1978)
CECPI/T31	Rapport du symposium sur la nutrition des poissons et la technologie de leurs aliments artificiels (1978)
EIFAC/T32	The value and limitations of various approaches to the monitoring of water quality for freshwater fish (1978)
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CECPI/T34	Essais CECPI d'interétalonnage des engins de pêche (1979)
EIFAC/T35	Report of the EIFAC workshop on mass rearing of fry and fingerlings of freshwater fishes (1979)
CECPI/T35	Rapport du stage CECPI sur la production massive du frai et des alevins en eau douce (1979)
EIFAC/T35 Suppl. 1	EIFAC Workshop on mass rearing of fry and fingerlings of freshwater fishes Papers (1979)
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CECPI/T36	Rapport du groupe de travail de la CECPI, de l'UISN et du CIEM sur la normalisation de la méthodologie dans la recherche sur la nutrition des poissons (1980)
EIFAC/T37	Report on combined effects on freshwater fish and other aquatic life of mixtures of toxicants in water (1980)
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EIFAC/T42 (Suppl.)	Documents presented at the Symposium on stock enhancement in the management of freshwater fisheries, Volume 1: Stocking, Volume 2: Introductions and Transplantations (1984)
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EIFAC/T43	Water quality criteria for European freshwater fish. Report on chromium and freshwater fish (1983)
CECPI/T43	Critères de qualité des eaux pour les poissons d'eau douce

	européens. Rapport sur le chrome et les poissons d'eau douce (1983)
EIFAC/T44	Report of the EIFAC working party on stock enhancement (1984)
CECPI/T44	Rapport du groupe de travail de la CECPI sur l'amélioration des stocks (1984)
EIFAC/T45	Water quality criteria for European freshwater fish. Report on nickel and freshwater fish (1984)
CECPI/T45	Critères de qualité des eaux pour les poissons d'eau douce européens. Rapport sur le nickel et les poissons d'eau douce (1984)
EIFAC/T46	Water quality criteria for European freshwater fish. Report on nitrite and freshwater fish (1984)
CECPI/T46	Critères de qualité des eaux pour les poissons d'eau douce européens. Rapport sur les nitrites et les poissons d'eau douce (1984)
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