Technical Briefing

Development of a mobile airlift pump for scientific divers and its application in sedimentological underwater research

Richard Stanulla*[1,2], Gerald Barth[2], Robert Ganß[1,2], Matthias Reich[3] and Broder Merkel[2]

[1] *CMAS Scientific Diving Center Freiberg, Akademiestr. 6, 09596 Freiberg, Germany*

[2] *GeoWiD GmbH, Morseweg 44, 01129 Dresden, Germany*

[3] *Institute of Drilling Engineering and Fluid Mining, TU Bergakademie Freiberg, Agricolastraße 22, 09596 Freiberg*

Abstract

To make the advantages of airlift pumps accessible for scientific divers working on geoscientific topics, the authors developed a mobile airlift pump that operates without any surface support. The device is powered by standard scuba tanks and has a quite slim design. Thus, it can be easily transported by scuba divers with lifting bags. The construction is based on the laws of Bernoulli and Boyle-Mariotte: a defined amount of gas supplied at the lowest point of a vertical, semi-closed system will expand while ascending and cause a negative pressure at the bottom. The development and practical testing was carried out in various lakes in Germany and in the Mediterranean Sea during fieldwork in the hydrothermal system of Panarea, Italy. There, chemical erosion led to sediment-filled cavities with diameters of several decimetres that are aligned along geological fractures. The removal of sediment is the main requirement to document the unique but covered lithological structures.

1. Introduction

The investigation of submarine geological structures is often hindered by a sediment cover. A detailed analysis necessitates the removal of this decimetre-thick sediment layer. An established method is the use of airlift pumps.

The principles of airlift pumps have been known since the end of 18th century, when Löeschner (1797) invented the first industrial airlift pump for its application in underground mining. In professional diving, airlift pumps are used for excavations and cleaning processes, e.g. the removal of sediment from archaeological items. Usually, these devices are supplied with a constant gas flow from a supporting vessel. This ensures nearly unlimited operational hours of the device and advantageous suction-power potential. However, long supply lines are necessary to operate the airlift, causing severe problems for divers in currents and greater water depth.

In addition, air-powered suction sampling is applied by marine biologists to collect specific taxae from the seabed. In this case, the ejector is equipped with a sampling net to catch the individuals of interest (e.g. Linnane et al., 2001; Templado et al., 2010; Ringvold et al., 2015). To make the advantages of airlift pumps accessible for scientific divers working on geoscientific topics, the authors developed a mobile airlift pump that operates without any surface support.

2. Technical requirements and fluid dynamics

As general concept, a mobile airlift pump had to be developed to work without any surface supply during operation. The pump will be operated by two to three divers at an operating depth of 5 m to 40 m below the water surface. Surrounding water temperature will range from 4 °C to 30 °C. The device must work as well in salt water as in fresh water environments and withstand respective types of corrosion.

The tool must be able to deal with sediments of various compositions and different grain sizes. This includes fine, adhesive clay and silt, abrasive gravel and any combination in between. Therefore, a

---

* Contact author. Email address: science@geowid.de
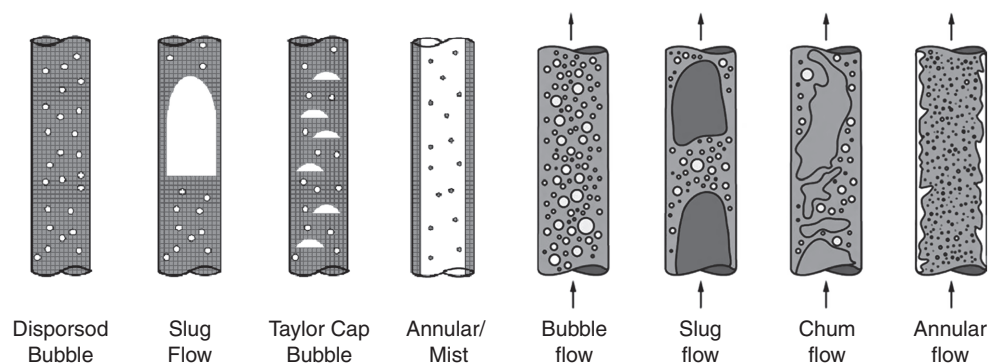
Fig 1: Various bubble types (left; USNRC, 2007) and types of flow (right; Mahrous et al., 2013) control the efficiency of the airlift pump. The annular flow represents the optimal mixture.

diameter of 50 mm to 300 mm at a rising height of 1.5 m to 5 m has to be applied to generate different amounts of suction power. The general grain size ranges from silt to fine-gravel. Air supply is realised by on-spot reservoirs (scuba tanks). The optimisation of suction power and air consumption is the most challenging task in the complex fluid dynamic system that is the 'airlift pump'. Despite the grain size of the sediment and the technical parameter of the pump itself, the flow model is a central point. Inside the pipes prevails a mixture of water, gas and sediment (multiphase flow). Especially regarding differences in the bubble-type (Fig 1), the amount of air in the mixture and the number of components in the flow are crucial topics for process optimisation. A continuous annular multiphase flow was found to be the most efficient. This means that as many small, similar shaped bubbles as possible have to be produced. Too large bubbles will cause the sediment to fall through the air-filled space. A small amount of air will be less effective.

3. Technical data prototype

The device is powered by three standard scuba tanks (15 L, 200 bar each) and has a quite slim design. Thus, transportation with normal lifting bags (~50 kg) by the operating diver is possible. The construction has an inner diameter of 5 cm (2″) and a rising height of 3 m being lifted by a standard diving buoy to stabilise the system. The intake (suction hose) has a diameter of 36 mm and a length of 1.5 m to 3 m in the tested configuration (Fig 2). A long suction hose is beneficial, as it ensures a sufficient distance between the operating diver and the ejector of the airlift pump. To keep the construction slim and unsusceptible to errors, its point of ejection is kept simple and without a sediment chute to carry the ejected material away. This means that the positioning of the airlift at its place of deployment is crucial. If there is any bottom current, the tool has to be placed downstream – away from the working
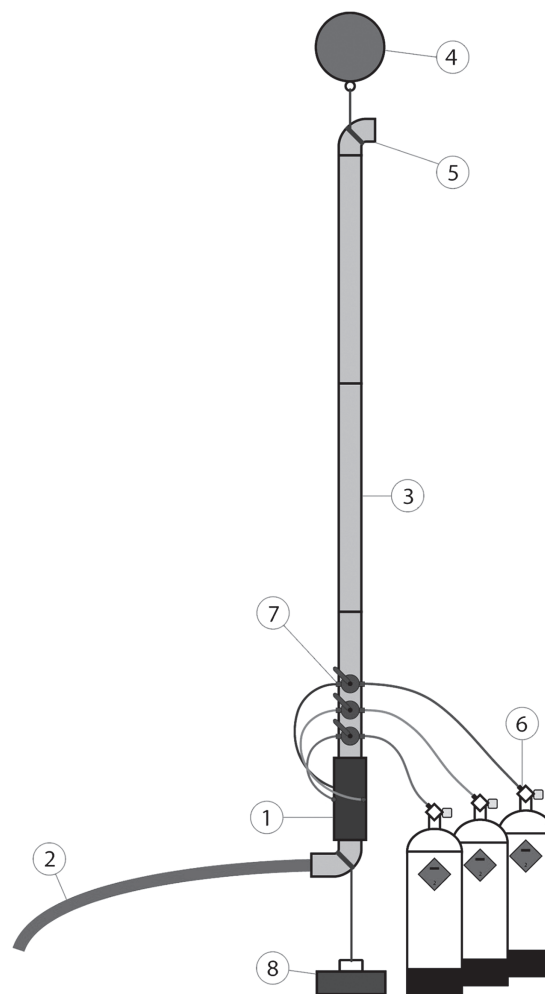
Fig 2: Technical model of the current prototype version. Major components: (1) mixing chamber gas injection, (2) suction hose, (3) riser pipe, (4) buoy, (5) ejector, (6) reservoir with supply-lines, (7) control panel, (8) counterweight.

area. Otherwise, the ejected material will fall back onto the working area or the divers.

The pump is fixed by counterweights of 16 kg. Approximately 10 bar working pressure is constantly derived as low pressure from a first stage regulator being installed to the air reservoir. However, an on/off set-up was deployed to keep the system as simple as possible.

2

One device could be manufactured as rough version at costs of approximately €500, excluding the scuba tanks and regulators. The theoretical background of the construction is rather simple: gas is supplied to a vertical, semi-closed system at its lowest point. According to the laws of Bernoulli and Boyle-Mariotte, it will expand while ascending inside the tubing. The displaced water causes a depression at the suction hose. As the present system is open on both sides of the tubing, a continuous flow is induced.

The construction is composed of three main groups of components (Fig 2):

1. a mixing chamber where the gas is injected (connections arranged in one level every 120°);
2. a suction hose that is connected to it; and
3. a riser pipe in which the multiphase mixture (water, gas, sediment) ascents and is ejected.

The present version is characterised by a rising height of 3 m, which causes a pressure difference of 0.3 bar between the suction hose and the sediment release. Although this version is optimised for the removal of sediments with grain sizes from clay (< 63 μm) to fine gravel (2–6.3 mm), other fractions would be possible by modifying the dimensions; the larger the rising height, the larger the suction power and thus the larger the transportable grain size. The optimisation of this correlation is very complex and depends on the rising height, the sediment type, the shape of bubbles and some other parameters. A detailed discussion would go beyond the scope of this article.

To start the airlift, the operating diver turns on all three air-supply lines. The use of single supply lines is not recommended: the mass-flow is limited at each supply line and is optimised for a three-tank construction. Using only one or two tanks lowers the effectiveness of the airlift. The suction power is generated and the excavation can be conducted (Fig 3). After finishing the cleaning or at a critical pressure in the reservoir tanks, the work has to be stopped and the whole system has to be flushed by clear water to prevent the clogging or reflux by or of sediment. Finally, the system is shut off, deconstructed and transported to the surface.

4. Results

Field tests were carried out in various lakes in Germany for engineering purposes, as well as in the Mediterranean Sea during fieldwork on submarine hydrothermal structures at the coast of Panarea, Italy.

The mapping of small-scaled hydrothermal fluid discharge structures is a good example of a typical application of the airlift pump. The discovery and
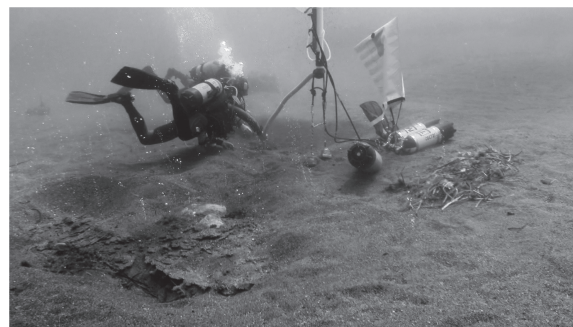
Fig 3: Excavation site in Panarea. Reservoirs, the counterweights and operating divers are all visible.

sampling of such fragile items (Fig 4) would be nearly impossible without this technical aid. The samples give evidence for early diagenetic stages of sedimentary fluid escape structures. The locations in Panarea are characterised by a notable volcanic activity. Hydrothermal alteration in particular forms the rock surfaces as aggressive fluids discharge at temperatures around–130 °C. The resulting chemical erosion and precipitation lead to sediment-filled cavities (Fig 5) with diameters of several decimetres that are aligned along geological fractures. These are buried under a sandy-gravely sediment cover with a thickness of several decimetres. The removal of this cover is essential to document the unique lithological structures beneath it. These are proving to have a complex sedimentary history and intense diagentical processes (Pohl et al., 2010; Stanulla et al., 2013; Stanulla et al., 2016).

The mobile airlift pump is not a substitute for surface-supplied airlift dredging devices. It is rather designed for in-situ small-scale excavation of delicate objects or structures.

A combination of only a few parts and a slim design grants many benefits on mobility and transportability either above or under water. Under water, the airlift can be transported with standard lifting bags (50 kg). As there is no need for a surface supply, the divers are able to choose the most suitable deployment location, and are also unaffected by waves and surface currents. Since the apparatus is powered by compressed air only, there is no pollution by oil, fuel, combustion gas or aggregate noise. Furthermore, the used materials are carefully selected for environmental sustainability (e.g. high-density polyethylene (HDPE) tubings that are food safe).

Of course, the mobile design comes with some drawbacks: because the air supply is realised by standard scuba tanks, the working hours are limited. Our field tests were carried out in water depths of 22 m to 26 m, and by the time the reservoir ran out of air (ca. 30 min), we were close to decompression (Fig 6). Nevertheless, it is possible to change

Fig 4: Workflow of an airlift excavation: from a sandy burial to the sampling of unique small-scaled sedimentary structures. Location: Panarea, Italy (water depth = 21 m).
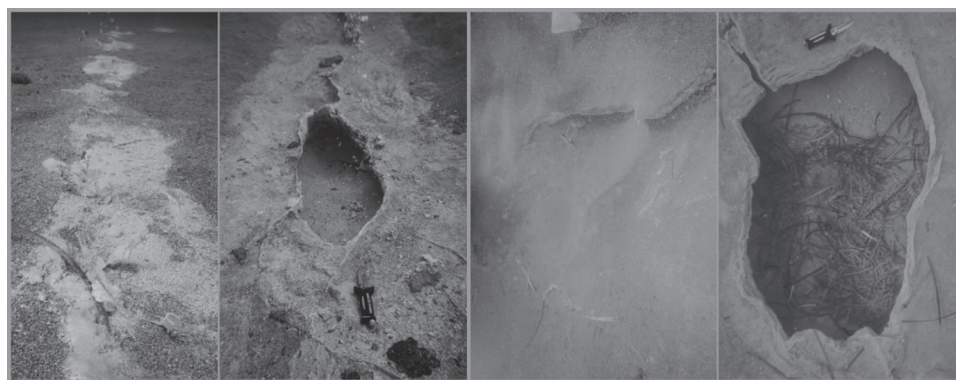
Fig 5: Before and after documentation of excavation sites in Panarea, Italy (water depth = 26 m). The diverse morphology of the volcanoclastic sedimentary rock would not be accessible without sediment removal. The investigations give insights in the genetical and diagenetical processes during sedimentation and hydrothermal alteration.
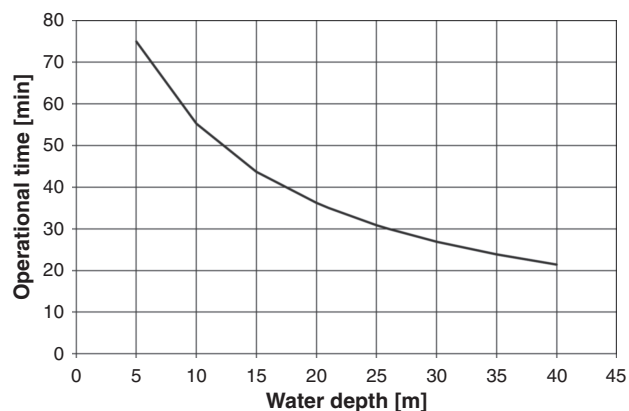
Fig 6: Empiric determination of the effective working hours of the mobile airlift pump (diameter riser pipe: 5 cm) at different water depths. Assumption: reservoir size of three 15 L standard scuba tanks with 200 bar.

Table 1: Advantages and disadvantages of the mobile airlift pump. This method is especially suitable for small-scaled structures demanding a mild removal of the sediment-cover.

Advantages	Disadvantages
Mobility	Limited operation hours
No need for a surface supply system	Limited suction power
Minimised influences of waves, currents	Optimised set-up is crucial
Environmental sustainability (e.g. no oil)	
Simple handling	
Low cost	
Transportation with normal lifting bags	
Mild removal of sediment cover possible	

these tanks underwater to extend this time. Preferably, 300 bar tanks should be used to prolong the operating time. As it is designed for the exposure of fragile objects beneath a sediment cover, the suction power is purposefully limited. If the sediment grains are comparatively coarse and elongated or disc-shaped, a clogging might occur. This also happened when too much sediment was fed to the airlift pump without flushing the system by holding the suction hose into the water column for a few seconds. In most cases, the clogging could be fixed under water very quickly.

When there is no need for an unlimited supply of a high flow-rate, the mobile airlift pump is a real alternative with respect to low cost, high mobility, easy handling and cautious sediment removal (Table 1).

5. Conclusion

The calculation of effective working hours is based on experimental data gained during excavations at two different water depths (Fig 6). A varying mass-flow (air) was measured in different depths that represent the base for the consideration of a depth-dependent mass flow of air. The air consumption depends on a variety of different influencing parameter. Despite the water depth, the design of

the mixing chamber and the transported amount of sediment are crucial. The type of sediment has a major impact. Furthermore, the air's volume changes non-linearly while rising. These facts influence the air consumption of the airlift. As a consequence, its gas-consumption curve has non-linear characteristics as one might expect due to the linear increase of ambient pressure. A distinct calculation would necessitate a complex mathematic calculation. The provided estimation instead gives orientation values for work and dive planning. Therefore, sufficient training and good experience of the working diver are necessary.

References

Linnane A, Ball B, Mercer JP, Browne R, van der Meeren G, Ringvold H, Bannister C, Mazzoni D and Munday B. (2001). Searching for the early benthic phase (EBP) of the European lobster: a trans-European study of cobble fauna. *Hydrobiologia* **465**: 63–72.

Loeschner CJ. (1797). Erfindung eines aerostatischen Kunstgezeuges. Verlag S.U. Crusius, Leipzig.

Mahrous A-F. (2013). Airlift pump with a gradually enlarged segment in the riser tube. *Journal of Fluids Engineering* **135**: 031301.

Pohl T, Becke R, Ganß R, Stanulla R and Merkel B. (2010). Small scale recent sulfide mineralization in a shallow submarine environment. In: Proceedings of the 2nd International Workshop on Research in Shallow Marine and Fresh Water Systems, 3–10 October, Milazzo, Sicily, 64–66.

Ringvold H, Grytnes J-A and van der Meeren GI. (2015): Diver-operated suction sampling in Morwegian cobble grounds: technique and associated fauna. *Crustaceana* **88**: 184–202.

Stanulla R, Pohl T and Merkel B. (2013): Laminated mineral precipitates in gas and water escape structures from the shallow marine hydrothermal system in Panarea, Italy. In: Proceedings of the 3rd International Workshop on Research in Shallow Marine and Fresh Water Systems, 14–15 February, Bremen, Germany.

Stanulla R, Pohl T, Müller C and Merkel B. (2016): Geological record of (sub-) recent gas- and water escape structures in the shallow marine hydrothermal system of Panarea, Italy. In press.

Templado J, Gustav P, Gittenberger A and Meyer C. (2010). Sampling the marine realm. In: Eymann J, Degreef J, Häuser C, Monje JC, Samyn Y and VandenSpiegel D. (eds) *ABC Taxa Vol 8. Manual on Field Recording Techniques and Protocols for All Taxa Biodiversity Inventories and Monitoring.* ABC Taxa, 273–307.

U. S. Nuclear Regulatory Commission (USNRC). (2007). *TRACE V5.0 Theory manual: Field equations, solution methods, and physical models.* Washington, DC: USNRC.