MINING AND TRANSPORT

OF

URANIUM CONTAINING BLACK SEA SEDIMENTS

by

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ABSTRACT

The main subject of this study is to apply submersible motor pumps with water-filled motor in mining the sediments from the bottom of Black Sea of which the upper ca. 1 meter layer with extension of 150.000 sq.km and with the sea water depth of 2000 meters has a natural uranium content 0.520 x 10^{9} tons (1).

Besides submersible motor pump system, other available mining systems are shortly described considering that one of them might be utilised in other deep-sea processes in conformity with the special requirements of application.

ÖZET

Yaklaşık 2000 metre derinliğe sahip, 150.000 km^2 sahaya yayılmış Karadeniz dip çamurunun yaklaşık 1 metrelik üst tabakasının içeriği olan 0.525×10^6 ton tabii uranyumun (1) çıkarılması için dalgıç motopomp sisteminin tatbik edilmesi bu çalışmanın ana konusudur.

Tatbikatın özel gereksinimlerine uygun olan diğer derin deniz proseslerinde faydalanılabileceği düşüncesiyle, dalgıç motopomp sistemi dışında, diğer mevcut çıkartım sistemleri de kısaca anlatılmıştır.

LIST OF SYMBOLS

Symbol	Definition	Unit
$\dot{M}$	Mass flow	kg/s
L	Length of piping	m
D	Diameter	m
	Density	kg/m^3
C_T	Mixing concentration by volume	%
$\dot{V}$	Volume flow	m^3/h
μ	Mixing proportion considering effect of weight	–
η	Efficiency	–
v	Velocity	m/s
Fr	Froude's number	–
g	Acceleration of gravity = 9.81	m/s^2
T	Immersion depth	m
Δp	Pressure losses	Bar
	Friction coefficient	–
H	Pump head	m
N	Shaft power	kW
S	Pipe cross-sectional area	m^2
Q	Capacity	m^3/h
n	Pump speed	R.P.M.
f	Frequency	Hz
V	Voltage	Volt
E	Energy	kWh
k	Pipe wall thickness	mm
W	Weight	Ton

Indices to be understood for

s	sediments
w	water
Tot	total
m	motor
p	pump
PR	pressure
SU	suction

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CHAPTER I

INTRODUCTION

1. BACKGROUND

As energy demand throughout the World increases, Nuclear Energy is becoming a more promising alternative energy source to meet this demand in the coming decades.

The fuel of Nuclear Energy is mainly Uranium metal and its production has been under the monopoly of certain countries. Since Turkey has already plans to build nuclear reactors in order to meet its own energy demand in the years to come, reliability of fuel supply becomes a primary concern. It may be that even economically marginal domestic sources of fuel may be of importance from this point of view.

On this respect, trying to find large uranium reserves of economic value and their evaluation is an important problem requiring continuous attention.

According to the results of investigations and experiments (1,2,3,4) the upper ca. 1 meter layer of Black Sea basin sediment with extension of 150.000 sq.km and with the Sea water depth of 2000 meters has a natural uranium content 0.525 x 10^6 tons (1).

Energetically, self-sufficient burning of the upper 1 meter strata is said to lead to uranium concentrations in the order of 7 gr per ton ash (1).

In order to evaluate this reserve, the application of submersible motor pumps with water-filled motor in mining the sediments from the bottom of Black Sea will be the main subject of this study.

1.1 THE MECHANISM OF URANIUM CONCENTRATION IN BLACK SEA SEDIMENTS AS A FUNCTION OF CHANGING HABITAT

The Black Sea is the largest anaerobic water body in the World and measures almost half a million sq.km (5). Its present enviromental state is a consequence of Holocene sea level rise and associated formation of a stable pycnocline restricting free exchange of molecular oxygen to the deep water (6). Holocene sediment cores from the euxine abyssal plain show, almost in slow motion, the development from a fully oxygenated fresh water 'Black Lake' to the modern brackish-marine Black Sea (7). A typical 1 meter sediment section consists from top to bottom of: coccolith ooze, sapropel, and light lutite. The sapropel-lutite boundary, with an assigned age of about 5000 years marks the event when the Black Sea became permanently stratified and euxinic conditions established at the sediment-water interface (8).

Fluctuations in redox potential may cause depletion or enrichment in certain elements both for water and sediment.

1.2 SAMPLES AND ANALYTICAL PROCEDURES

The uranium content in abyssal Black Sea mud is almost one order of magnitude larger than in average marine sediment (9,10). Similar concentrations are known from sediments of Norwegian fjords and the Baltic Sea (11,12). It seems, therefore, that restricted environments with a trend to euxinic conditions favour accumulation of uranium.

In the Black Sea abyssal mud the U_3O_8 concentration rarely exceeds 20 ppm and [illegible] ppm can be accepted as a representative value (7). In spite of this uranium level and the areal distri-bution, the anomaly seems to be, on first sight, of no economic significance. This outlook, however, may change by closer examina-tion of the deposit from a sedimentological and geochemical point of view. This is because the high content of [illegible] and carbonate may allow for a considerable reduction in sedimen[illegible] mass by burning; furthermore, the material is unconsolidated and thixotropic.

Water and sediment were collected during RV Chain cruise of the Woods Hole Oceanographic Institution in Spring, 1975. Location of stations is shown in Fig.1. The sample collection has been supplemented with Pleistocene sediments obtained durin[illegible] the deep-sea drilling operation of Glomar Challenger, Leg 42 in the Black Sea in May-June, 1975 (Fig.1).

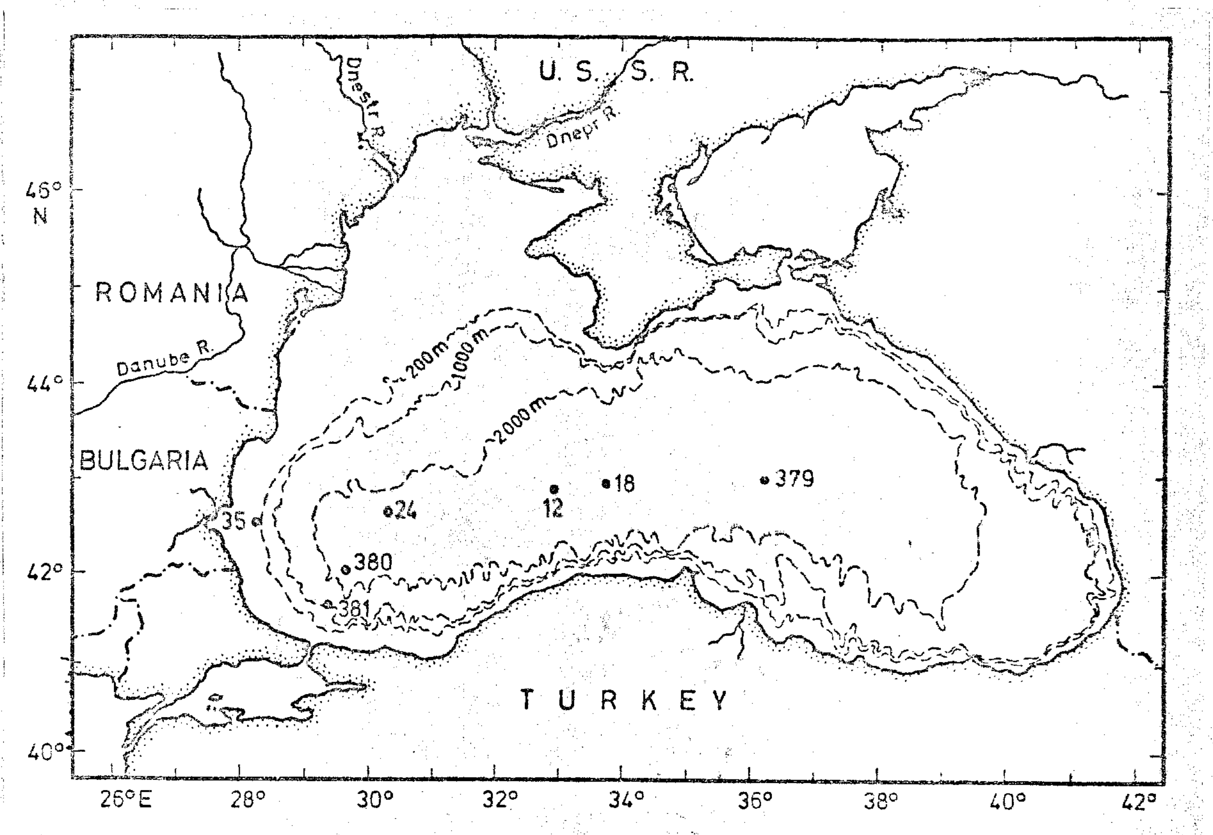


Fig.1 Bathymetric chart of Black Sea and location of stations

Uranium determinations were carried out spectrophotometri[illegible] using methods previously developed by F.Pakalns and [illegible] (13,14). Principally, uranium was extracted with tri-n-[illegible] oxide (TOPO); and 2-(5-bromo-2-pyridylazo)-5-diethyl-[illegible] (bromo-PADAP) was used as a chromogenic reagent. [illegible] was used as spike and synite rock SY-2 and SY-3 from Canadian certified reference materials project, Mines Branch, Ottowa, were used for intercalibration.

1.5 RESULTS OF SAMPLE TREATMENTS

The three stratigraphic units- coccolith, sapropel and lutite, can be distinguished by their carbonate and organic matter content (Table 1). The core section is close to station 379 (Fig.1). The carbonate fraction in the lutite unit is principally composed of reworked Cretaceous and Tertiary coccoliths, whereas in the sapropel and coccolith units it is authigenic.

Depth (cm)	Unit	$CaCO_3$ (%)	Organic C (%)	Organic N (%)
2		41.[illegible]	3.86	0.35
5		56.2	3.84	0.33
8		34.9	3.53	0.31
12		60.7	4.31	0.37
15	Coccolith	65.7	5.10	0.44
18		48.2	5.17	0.44
22		14.9	5.91	0.49
25		16.5	7.17	0.60
28		11.0	11.45	0.95
32		16.5	12.23	1.11
35		12.4	13.45	1.18
38		7.8	14.35	1.24
42		8.9	15.73	1.25
45		6.9	14.10	1.26
48		6.9	16.85	1.38
52	Sapropel	3.4	19.90	1.41
55		5.0	18.65	1.37
58		3.4	17.42	1.15
62		3.8	15.35	1.02
65		4.3	15.50	1.01
68		12.6	4.70	0.39
72		6.0	2.07	0.19
75		10.2	0.31	0.030
78		10.7	0.45	0.032
82	Lutite	1.8	2.60	0.24
85		0.54	1.60	0.17
88		9.4	0.81	0.09
92		3.8	0.75	0.07

Table 1. The carbonate and organic matter content of the stratigraphic units (see ref.2)

The organic matter in the sapropel is principally land-derived, particularly at the base of the unit. Increase in carbonate content towards the top signals a progressively higher input of marine planktonic material.

The U_3O_8 content in the sediment matches closely this stratigraphic development. The fresh water lutite unit deposited in aerobic conditions shows the smallest enrichment, and the brackish-marine coccolith ooze at the bottom of the euxinic abyssal plain the highest one (Table 2, core 18). 'Dilution of coccolith ooze by detrial clay minerals going from the central basin towards the Bulgarian coast, that is from station 18 to 35, is reflected in a lowering of the U_3O_8 content in coccolith ooze (Table 2). On the basis of a few analysis from core samples drilled by Glomar Challenger a similar trend seems to be established. A calcareous mud (Table 2, 379A) deposited in aerobic conditions has little uranium, whereas the five remaining cores formed in an anaerobic environment show a 10-20 fold enrichment in U_3O_8. The highest values again are found in the two samples from the central basin (station 379A).

Table 2. The HU_3O_8 content of the stratigraphic units (see

Core	Sample	Depth	Wt-loss (%) 0–100 °C	Wt-loss (%) 0–1,000 °C	U_3O_8 (p.p.m.) (1)	(2)	(3)	(4)
	Coccolith ooze	4 cm	68.7	80.5	55.0	113.9	55.4	[illegible]
	Coccolith ooze	21 cm	66.0	77.6	59.7	34.6	9.0	[illegible]
18	Sapropel (top)	30 cm	65.5	74.6	23.4	17.3	40.4	[illegible]
	Sapropel (base)	85 cm	71.0	81.9	15.7	40.1		[illegible]
	Lutite	100 cm			2.4			
12	Coccolith ooze	10 cm	61.9		35.4			
24	Coccolith ooze	4 cm	66.5		28.3			
35	Coccolith ooze	30 cm	58.4	68.5	15.0			24.3
	Coccolith ooze	100 m	38.5		40.1		118.3	
379 A	Sapropel	100 m	24.6		49.5		95.8	
	Calcareous mud	231 m	35.3		2.4			
380 A	Carbonaceous lutite	673 m	25.6		35.4			
	Diatomaceous marl	837 m	30.5		20.4			
381	Diatomaceous mud	237 m	37.0		33.8			

(1) After drying at 110 °C; (2) after drying at 110 °C and treated with 10% cold HCl and washed with H_2O; (3) after drying at 110 °C hydrolysed with 6 M HCl for 22 h and washed with H_2O; (4) after ignition at 1,000 °C; (5) after ignition at 1,000 °C and washed with H_2O.

Treatment of sample material with HCl or water, or by the combustion, may cause uranium depletion or enrichment in the residue (Table 2). Of special significance is the high U_3O_8 yield of the mineral ash obtained in the combustion experiment, and the release of uranium by extracting the sapropel ash with water

U_3O_8 concentration diminishes because of:

1. Loss of mineral-bound water,
2. Loss of sulphur-containing volatiles,
3. Loss of salts,
4. Calcining of carbonates, and
5. Burning of organic matter.

U_3O_8 depletion is caused by:

1. Acidification,
2. $CaO-H_2O$ interactions, and
3. Release of water soluble uranium-organic complexes.

The bulk of the uranium seems to be bound to planktonic matter; land-derived organic debris contains comparatively little uranium. Coccoliths seem to be the prime host for uranium in modern Black Sea sediments, but other planktonic organisms share this affinity (15). The following tentative model is suggested to account for the enrichment.

Eukaryotic cells contain complex membraneous organelles known as the Golgi apparatus or Golgi body which occupy a central position in the transport system of the cell. For example, they fix and transport metals from within the cell to the outer membrane. This is accomplished by metal-ion coordination to specific proteins and polysaccharides which are subsequently transported to the outside. Biomineralisation is an outgrowth of this process (16). In the case of the coccoliths, uronic acids and polysaccharide sulphates (17) are the principal metal-ion fixers. The relationships are revealed by an electronic micrograph where the organic template is stained by heavy metals, thus revealing the growth pattern of the coccolith within the Golgi body. In this way, metal ions that are not needed by the organism can be readily neutralised.

Uranium content of Black Sea water ranges from [illegible] to 7 ppb (parts in [illegible]) with the average 3 ppb (18,19) which is about the value for standard mean ocean water. U_3O_8 values are within the same order of magnitude: aerobic zone (2.4 ppb), interface (5.9 ppb) and anaerobic zone (3.5 ppb). Assuming that coccoliths fix the uranium principially during the life cycle of the organism a 10.000 fold enrichment is observed.

Marine calcareous material of biological origin is reported to contain at most a few ppm uranium (20). In general, carbonates are less favourable host materials for uranium (21). Thus, the enrichment of U_3O_8 in the Black Sea coccolith unit is unexpected. In view of the nature of the calcifying matrix in coccoliths, however, the uronic acids and sulphated polysaccharides act as a substrate in the formation of hexavalent uranium complexes.

Non-calcareous plants may operate in the same fashion if their cell walls contain such sugars as they do in diatoms. Studies on a [illegible] lake in central Ontario, for example, which is polluted by discharge from an uranium mine shows a 10.000 fold U-enrichment in the diatom-dominated living plankton over the water, that is 210 ppm against 20 ppb. The sediments, at a water depth of 10 to 25 meters, are principally diatomite and reducing in character, their U-content is between 170 and 380 ppm. It thus seems that reducing conditions in the depositional environment are only essential for the preservation of uranium-enriched detritus and not for the fixation. Following sedimentation, a series of organic molecules may pick up additional increments of uranium as well as other heavy metals from sediment and water. The organic material can become stabilized by heavy metal complements to a point that it is finally rendered insoluble to extraction by conventional acid or base treatments.

1.4 MASS BALANCE

The Black Sea covers an area of 4.23 X 10^5 sq.km, of which [illegible] is shelf. The basin proper, therefore, has an areal extent of [illegible].96 X 10^5 sq.km. Nearly half of this area has a depth of 2000 meters where uranium content in sediments is hoped to be the maximum. Hence mineable area seems to be 150.000 sq.km. The top 1 meter sediment has a bulk density of

2.5 gcm^{-3}, which will give a sediment mass of 3.75×10^{17} g. Combustion of total sediment at $1000^{\circ}C$ will reduce weight of material by 80%; weight of remaining ash is 7.5×10^{16} g. Average U_3O_8 content in ash (1) is 7×10^{-6} g per g sediment. Total U_3O_8 concentration in sediment ash of top 1 meter strata of Black Sea basin is, therefore 5.25×10^{11} g or 5.25×10^{5} tons.

Sapropel and coccolith ooze have been deposited over the past 5000 years. Assuming that uranium is extracted at a constant rate over this time, the basin sediments will annually receive 1.05×10^{8} g U_3O_8. Should this material exclusively be extracted from the aerobic water layer having a mean U_3O_8 content of 3×10^{-6} gl^{-1} (2) or a total of 9×10^{10} g U_3O_8 for the upper 200 m, about 0.1% of this amount is annually released into the sediment.

1.5 CALORIMETRIC DETERMINATION OF COMBUSTION HEAT

Average Black Sea abyssal mud deposited over the past 5000 years contains per 1000g sample: 600g H_2O, 100g clay, 100g organic matter, and 200g $CaCO_3$(2). Since combustion of sediment at $1000^{\circ}C$ will substantially increase the U_3O_8 content in the remaining ash, it is of considerable interest to know whether indigenous organic matter can supply sufficient energy for this reaction.

From this point of view the important reactions to be induced are;

Calcining of carbonates:

$$CaCO_3 \longrightarrow CaO + CO_2 \qquad E = 47.2 \ kcalmol^{-1}$$

and Evaporation of water:

$$H_2O\ (aq) \longrightarrow H_2O\ (g) \qquad E = 9.73\ kcalmol^{-1}$$

which require a total of 418 kcal per 1000 of sediment. This is the minimum amount of energy needed for self sufficient burning.

For three representative samples from station 18 (Fig 1), coccolith ooze, top sapropel, and bottom sapropel, combustion heat values was determined by Egon T. Degens, Francis Khoo and Nelson Michaelis using a conventional calorimetric bomb. These values are given in table 3 together with calorimetric values of common organic compounds.

Table 3. Combustion heat values for the stratigraphic units compared with common organic compounds

Sample	Combustion Heat ($Kcalkg^{-1}$ at $25^{\circ}C$)
Coccolith ¤	528
Top Sapropel ¤	642
Bottom Sapropel ¤	1109
Wood +	4500-4800
Peat +	5000-5800
Lignite +	6200-7600
Coal +	7600- 8750

¤ Samples were pre-dried at 110°C
+ See (22)

Combustion heat values for the dry mud samples are considered minimum values, because part of the heat generated during the experiment has been used for calcining, thermal degradation of clay minerals, and decomposition of sulphides. Still, these values are far in excess of the 418 kcal needed to dry and calcine a 1000g wet sediment.

In conclusion, heat of combustion of recent Black Sea mud will release more energy than is required for drying and thermal degradation of mineral matter. The combustion process will yield an ash with a U_3O_8 content close to 7 $g\,ton^{-1}$. Slightly higher values are expected in those parts of the Black Sea basin which are furthest removed from river outlets and turbidity incidents. Such a region would be close to station 379 (Fig.1).

In view of the high sulphur content of recent Black Sea mud a note of caution should be sounded, since mining of the low grade ore may introduce environmental hazards.

2. SCOPE

In the first part of this thesis, submersible pump with water-filled motor in deep-sea technology is described besides other available mining systems. The description of the pump is followed by a detailed description of the water-filled submersible motor will show that it is the water-filled type which is especially suitable for the application in deep-sea technology.

Design of a mining system, mining operation and special requirements for submersible motor pumps for deep-sea applications is given in chapter III.

In chapter IV necessary power for the [illegible] sediments from the Black Sea bottom is calculated [illegible] are introduced to simplify the transportation of mixture and to reduce the resultant pollution levels.

CHAPTER II

AVAILABLE SYSTEMS FOR MINING OF DEEP SEA SEDIMENTS

Continuous recovery of sea floor materials is a particular difficult undertaking because the environment at great depths is extremely hostile to both men and machines. Although there are many proposed concepts for lifting bodies of ore from the deep-sea, only four techniques are pesently receiving serious attention.

These techniques available for sediment collection, except the submersible motor pumps technique, will be described shortly. Then a detailed discussion of the application of submersible pumps with water-filled motor in deep-sea technology will be presented as the main subject of this section.

1. CONTINUOUS LINE BUCKET SYSTEM

The so-called continuous line bucket technique, which uses an endless bucket chain, has been public knowledge for years.

Such a mechanism that was tested in experiments in the Pacific by a group of Japanese companies depends on a 10-mi (16-Km) length of heavy polypropylene plactic cable. Attached to the line at 80-ft (24-m) intervals are specially designed dredge buckets each capable of scooping up from 1 to 5 tons of nodules. The loop is held open by two ships slowly steering parallel courses about 1/2mi (0.8km) apart. With the lower end of the loop touching the bottom and the endless chain set in motion by hydraulic drums on board the vessels, the dredge buckets successively deliver their nodules and drop them into the ships' houlds (23).

Due to the smaller grain-size of sediments, this system is not taken into consideration.

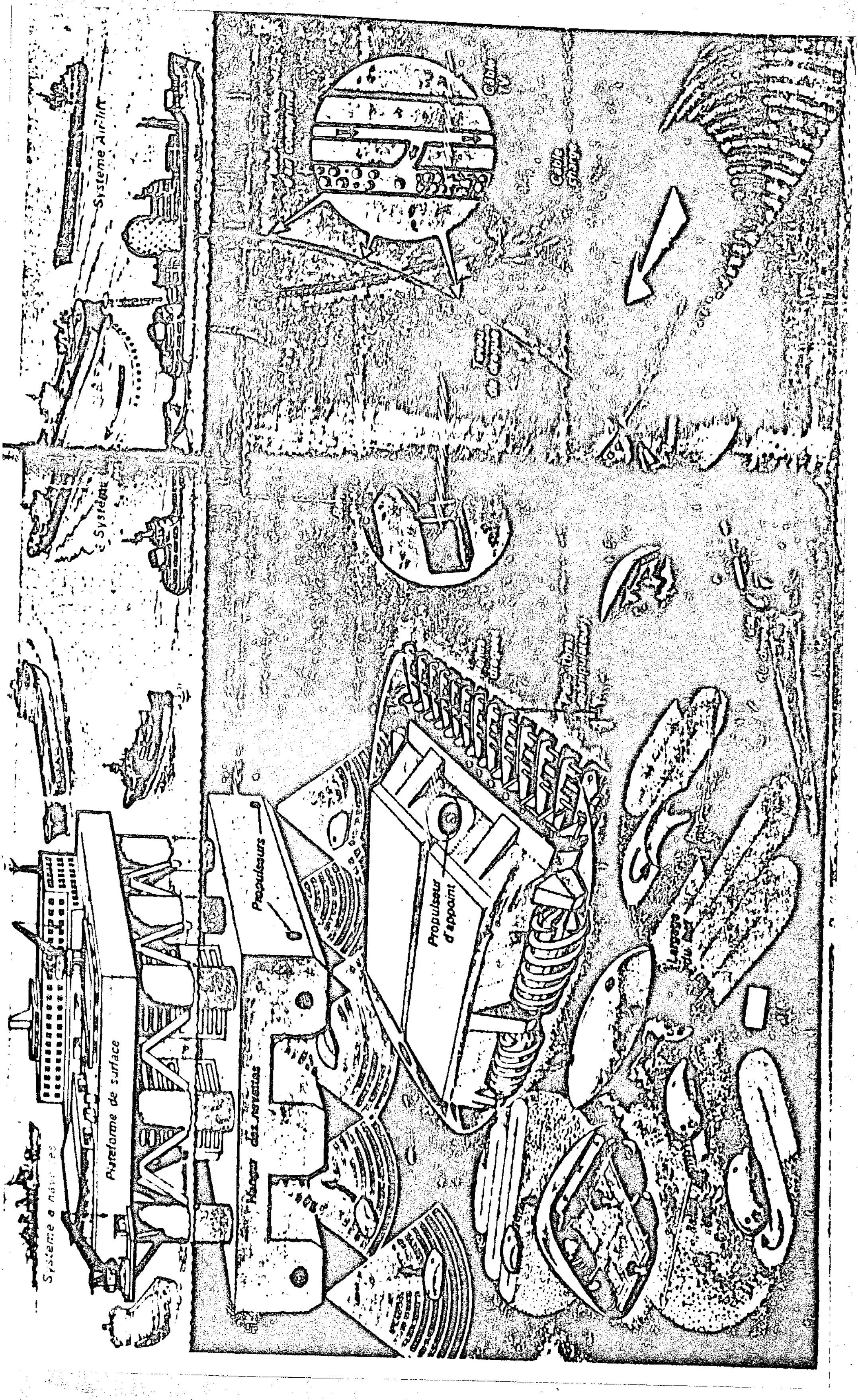


Fig.2. Continuous Chain Bucket System

2. AIR LIFT SYSTEM

By means of this technique, the indirect transport of solids can be achieved without using centrifugal pumps.

In this system, a main pipe, open at both ends, is immersed into the water near the sediment layer. At some depth of the sea which is calculated according to the requirements of the application compressed air is injected to this pipe through an auxillary piping. Compressed air creates suction pressure at the bottom of the main pipe and a water stream develops upward in the main pipe. This stream, also, collects the sediments and nodules located near the suction end of the main pipe (4).

Mechanism of such a system is represented in Fig.3.

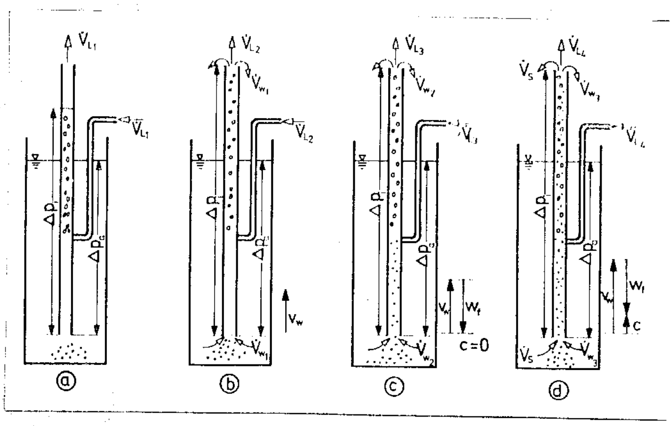


Fig.3. Principle of bulk material transportation operating on the airlift system.

3. TUBULAR CHAMBER FEEDERS SYSTEM

The hydraulic transport of coarse grained solids requires pumps which are exposed to an erosion wear with higher flow velocities by each deflection of the solids. For this reason, the velocities of flow, that is to say with centrifugal pumps the delivery heads also have to be limited. An indirect transport of solids by centrifugal pumps is not subjected to this restriction, because the solids do not pass principally through the pump within these systems. Such systems are known as tubular chamber feeders or pipe feeders (Fig.4).

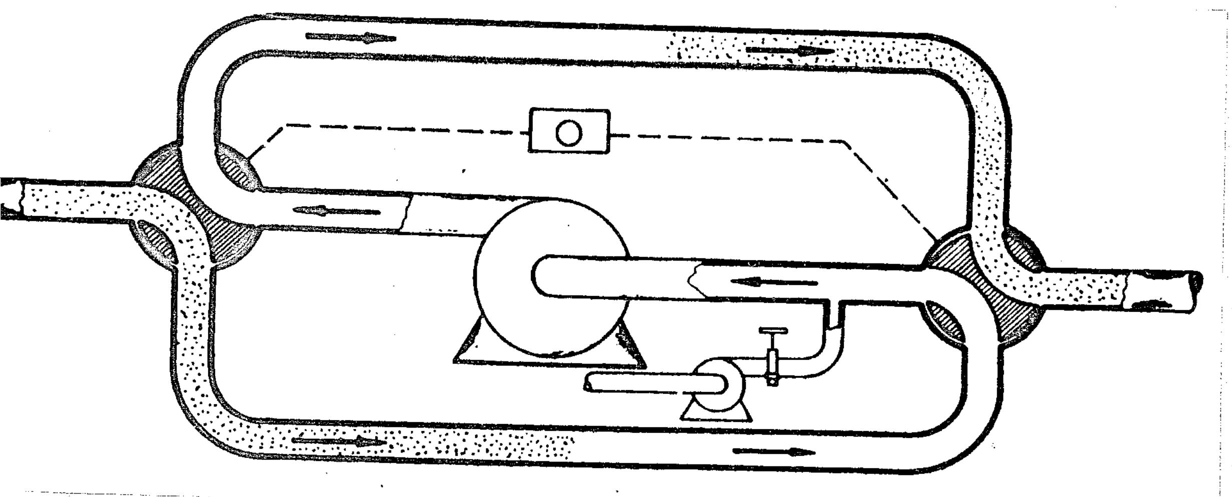
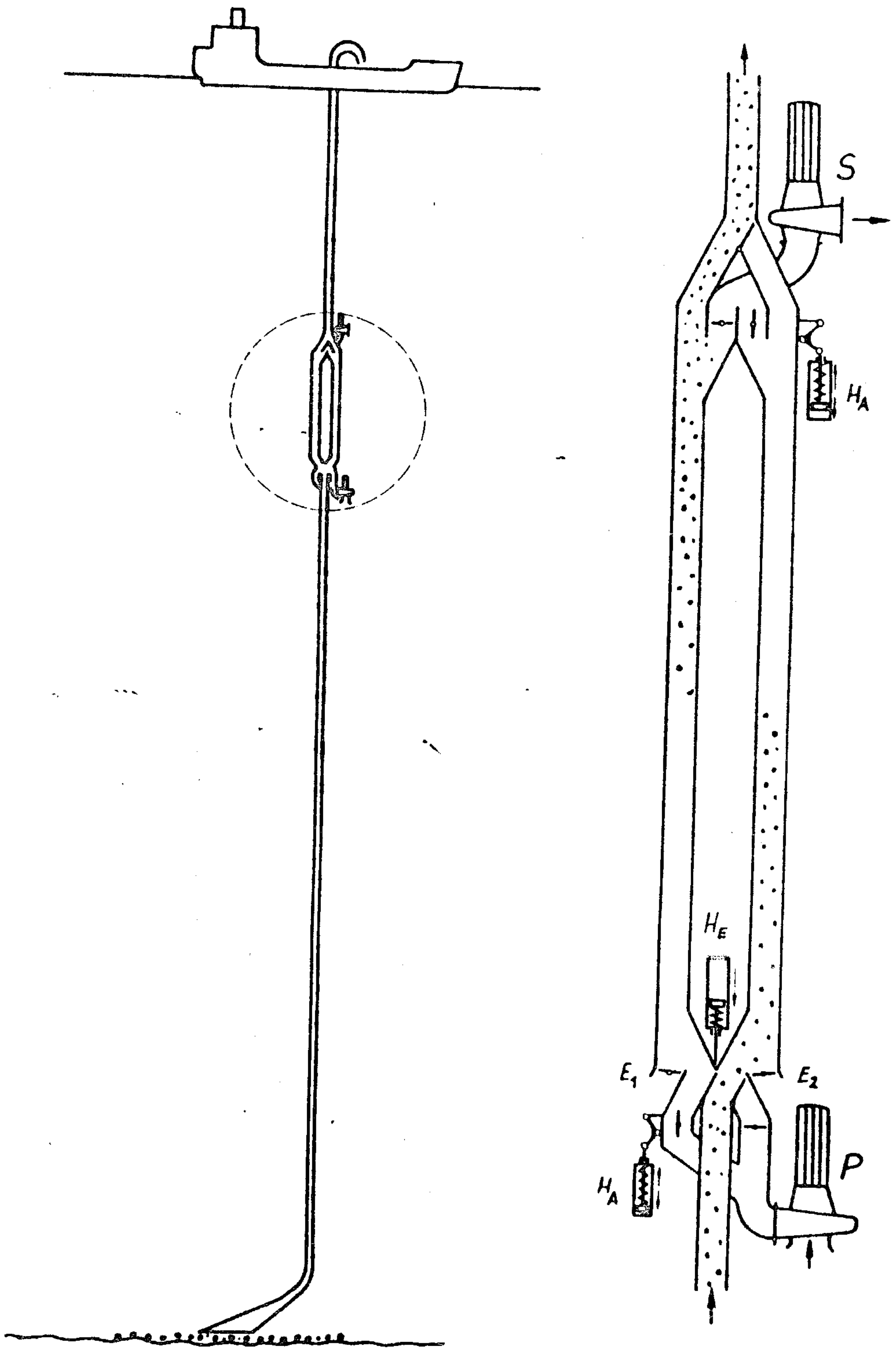


Fig.4. Pipe feeder in a two-cycle process with uniflow flushing. Proposal according to (25)

3.1 OPERATION PRINCIPLE

Such a mining system (26) would operate to the following principle (Fig.5).



[illegible] for the transport of manganese [illegible] by
[illegible] feeder (two-cycle process with [illegible]
[illegible] according to (27).

A double pipe, the bottom end of which is connected to a pressurized water pump PR, and the top end of which is [illegible] to a suction pump SU, is connected to these pumps in such [illegible] that the suction pumps draws the flow of solids alternately into one of the two parallel pipeducts, whilst the pressurized water pump simultaneously flushes the other pipe, and discharges its content into the discharge piping. If, after termination of the priming phase, the control valves A_1 to A_4 change over in due course, so that the suction pump then draws in the flushing water of the other piping, and if this process is permanently repeated to a regular cycle, then the flow of solids drawn in never reaches the suction pump.

While only clear pressurized water, i.e. no solid matter, flows through the controlled valves A_1 and A_2 which alternately connect the pressure pump PR to the two Pipe-ducts, the two other valves A_3 and A_4 which control the connection of the suction pipe SU, must be protected, since there might be residues after flushing of the pipe, and these residues should not enter the suction pump SU, if ever possible. This protection can be realised in a simple way by selecting the velocity of the flushing flow sufficiently higher than that velocity at which the solids flow into the system and fill up one of the two ducts (28). Thus, the rate of flow of the pressure pump PR must exceed the rate of flow of the suction pump SU in the same proportion.

Generally, the solids transported dispose of a broader grain spectrum, i.e. the diameter of the solids may be a very different one.

So, the particles of different sizes also move in the water at different velocities. After change-over of the parallel pipes, a barrier develops between the clear flushing water entering the pipe, and the mixture of solids and water already located in the pipe. This layer, sharply separating at firs, fades more and more in the course of the flushing process, as the bigger, slower particles lay behing the ideal barrier layer (the ideal barrier layer being that which would move on at the mean water velocity in the pipe). In bibliography, this velocity proportion has been described depending on the grain size, the transporting velocity and referred to horizontal pipes (29); regardingvertical pipe-lines; the velocities of descent of solids of uniform diameter are known (30); the separation processes resulting for a broad grain spectrum are just examined by the "Institüt für Fördertechnik" of the University of Karlsruhe.

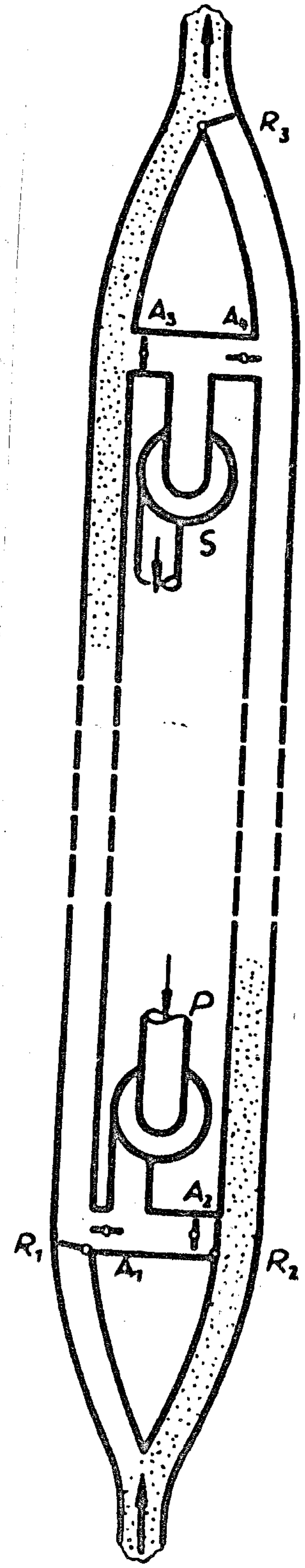
The system still needs some non-return valves R_1 to R_3 for good functioning, the upper R_3 of which can be protected by the same flushing water as the control valves A_3 and A_4 in front of the suction pump. Only the two non-return valves R_1 and R_2 at the entry of the pump system still need a special protection, e.g. by flushing those valves with clear water during closing.

The relatively high number of actuating the valves, depending on the velocity of the flow and the selected length of the pipe feeder, as well as the danger of a formation of surges in the main riser require controlled operation. As regards the four controlled valves A_1 and A_4, this means an actuation time of only some seconds. This must be duly considered when selecting the actuators. The non-return valves R_1 to R_3 which move automatically owing to the effect of the pressure differential.

Plugs in the two parallel pipe-ducts must operate with a similar lapse of time, i.e. their movement must be greatly damped; and, thus, operating in throttled condition when releasing only small cross sections, they will no more come into contact with solids. Since pressure variations in the parallel ducts so can form but gradually, surges in the riser main will be prevented.

The two actuators of valves A_1 and A_2 or A_3 and [illegible] respectively, arranged in pairs in each case, are preferably [illegible] hydromotors (H_A), the drums of which are moved against [illegible] spring assembly via the pressure differential of the pump [illegible]. Two solenoid-operated stop-valves will do to control the two hydromotors, these stop-valves being controlled from aboard to the same cycle.

Each of the two parallel ducts is fitted with an emergency outlet branch E_1 and E_2 respectively, the closure of which may [illegible] open if there are interruptions in operation of any kind, [illegible] ensure that the solids falling back will may leave the [illegible] so that they may not enter the pressure pump PR or the bottom [illegible] of the riser. These emergency flaps, too, may be closed by hydromotors H_A in such a way that flaps open automatically by the [illegible] of the spring, and that; as soon as the pressure pump does not deliver [illegible] water, [illegible] pressure [illegible] for any reason [illegible]



6.6 Schematic arrangement for indirect transport of manganese nodules by means of centrifugal pumps.

The driving motor of the suction pump SU should be switched in such a manner via impulse transmitter that it is only running if the pressure pump PR is working, too. Thus, the system is capable of protecting itself, together with all its components; if, for instance only suction pump is failing, the pumping station now continues working with clear water of the pressure pump PR and discharges the contents of the upper riser main above sea level. The velocity in the bottom main diminishes gradually and the solids finally fall back here. The emergency outlet branches E_1 and E_2 remain closed. During such a phase of operation there is no danger that the pumping station [illegible] clogged; the pumps and valves are protected. If, however, there is a failure of the pressure pump PR, there is a standstill of both pumps. Owing to the spring pre-load in the actuators, the valves A_1 to A_4 move into a final position, and the emergency outlet branches E_1 and E_2 open in the same manner. Now, the [illegible] of the [illegible] main fall back through one of the parallel ducts [illegible] through an emergency outlet branch, they leave the system, [illegible] to the solids in the other parallel duct. The solids in the [illegible] main continue falling back, until they are discharged from the pick-up device at the bottom of the sea. As in the case of every other pumping system, this pick-up device must be [illegible] out for these emergency requirements. Here, too, the [illegible] not become clogged, and all its components are [illegible] accordingly.

Under normal operating conditions, there is one further point within the pipe feeder that may be endangered by wear:

the branching at the lower end of the two pipe ducts (Fig.7) needs a protection, too, to reduce the impact effect of solids. The slight change in flow direction at this point may be eliminated by a superimposed transverse flow. It is a fact that the flow in a symmetric diffuser always presses against one of the side walls if a very small transverse flow is introduced into the flow from the opposite end. If, thus, a small pressurized water stream is alternately introduced into the two sides of the diffuser type branching, the flow immediately moves to the respective opposite side, and so into the parallel pipe located there; the solids adapting to this flow more or less. As regards the transverse flow, no value is required since the valves A_1 and A_2 can assume this function. If the branching of the pipe is of the streamline type, with radii of curvature as big as possible, wear on the point of branching, if any, might be so be reduced to such an extent that the availability time required may be attained without difficulties. As a measure of precaution, the critical points should be of wear resistant materials and dispose of big wall thicknesses.

The valves are mostly gate-valves, or, sometimes, cock valves. They ensure hermetical sealing of the pipes between the working cycles. Regarding manganese nodule transport, the valves and their actuators must be designed for minimum space and allowing slow pressure variations. These requirements are well met by flap or ball valves. The sealing flaps A_1 to A_4 for the pumps are placed in the clear sea water and may be designed as concentric flaps, i.e. as flaps which, if in their opened position still seal off an average portion of the passage cross section to a certain degree. The non-return valves R_1 to R_3 however, are located within the solids flow, i.e. they must be unilaterally guided, so that they will offer no resistance to the flow in their opened position, and, thus, not be subjected to wear. Such sealing flaps and non-return valves are, indeed, only seldom used nowadays but they can well be built owing to the present level of technology.

The application of such a system for mining of Black Sea sediments and its comparison with the air-lift method have been discussed in reference 31.

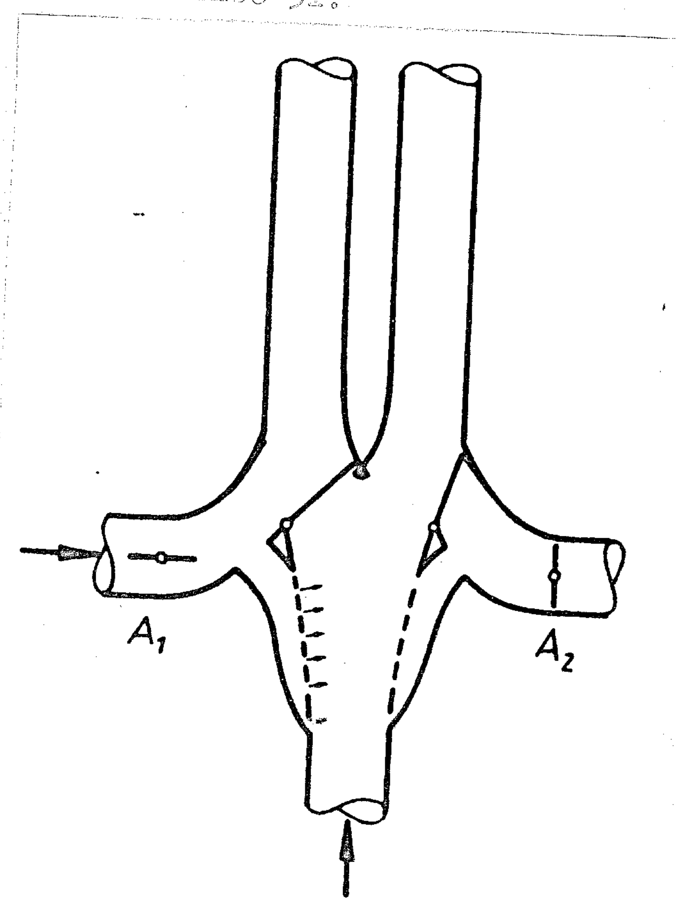


Fig.7 Guiding of the flow at the bottom inlet of a two cycle pipe-feeder.

4. SUBMERSIBLE MOTOR PUMP SYSTEM

The submersible motor pump owes its development to the demand for a pumping set capable of operating fully immersed in the liquid pumped, with complete reliability and also capable of operating without any facility of easy access, e.g. for maintenance purposes.

An important aspect in favour of the development of the submersible motor pump is the basic physical fact that the suction head of the pump operating in open circuit is limited by the barometric pressure.

Because of these considerations, the principal fields of application of the submersible motor pumps are:

- the winning of ground water out of deep wells
- the drainage of mines because of the floodability of the submersible motor pump.

During the last two decades, several entirely new fields of application presented themselves to the submersible motor pumps in the areas of off-shore and on-shore technology:

- the pumping of hydrocarbons stored in underground caverns
- various applications on drilling rigs and production platforms, e.g.
- as trim and ballast pumps
- as fire fighting pumps, because of their readiness for instant start-up at all times
- as cooling water pumps
- as bilge pumps

In deep sea technology, submersible motor pumps made headline news at the beginning of 1978. Before discussing this development in greater detail however, a brief description of the design and construction of the submersible motor pumps will be given in the following section.

4.1 DESCRIPTION OF THE DESIGN AND CONSTRUCTION

The main future of the submersible motor pump is its slim outline, which enables it to be installed in narrow and deep boreholes. Fig.8 illustrates two submersible motor pumps in cross section, with the motor depicted in shortened form. Because of the relatively small diameter of the pump, it is in most cases necessary to provide a large number of stages (impellers and diffusers) in order to attain the required total head (32).

Meanwhile, total heads in excess of 1000m have been achieved, and in the case of pumps equipped with mixed flow impellers (Fig.8), rates of flows in excess of 840 l/s (3000 m^3/h) have been attained.

Most submersible motor pumps are of single entry type, on condition that the axial thrust generated is capable of being absorbed by the thrust bearing located in the motor.

Fig.9 illustrates a double entry submersible motor pump with its associated driver. In this case, the hydraulic axial thrust is balanced almost entirely, and the thrust bearing arranged at the botton of the motor is only required to absorb the rotor weights.

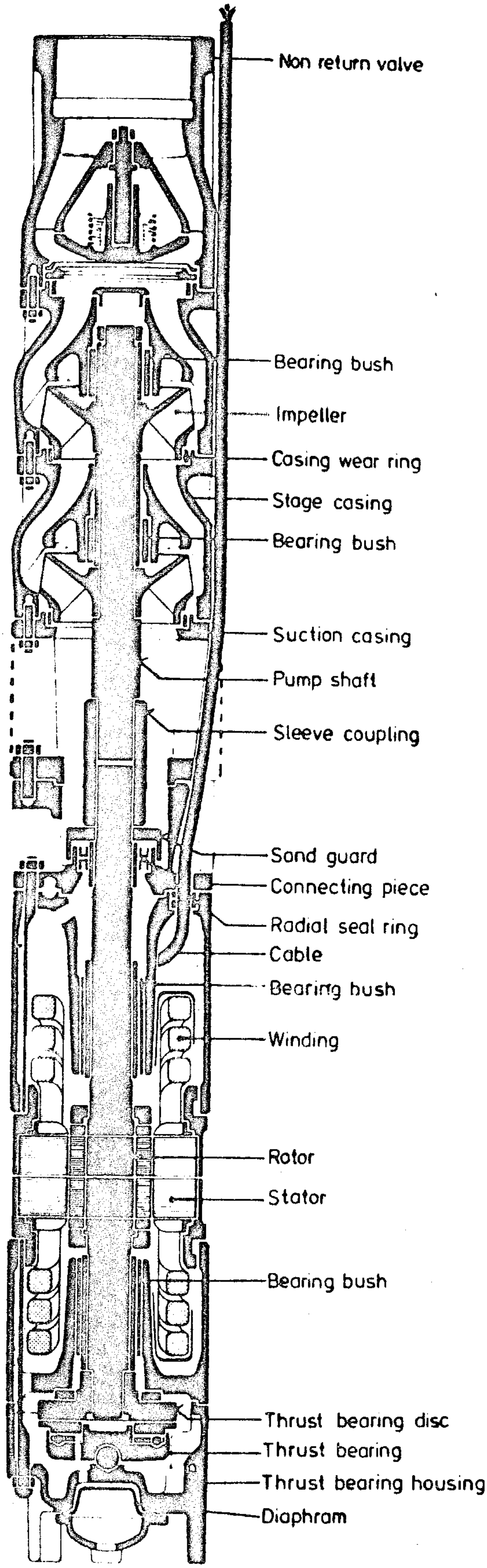


Fig.8 Submersible motor pump

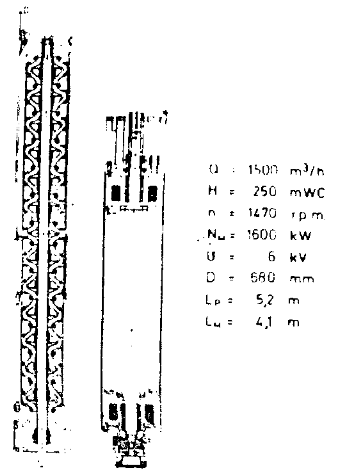


Fig.9 Double entry s
mersible pump with m

The design and construction of the pump, and in particular the design of the impellers and diffusers are governed by the limitations imposed on the diameter; this means that high pressure coefficients must be aimed for, without having at the same time to sacrifice efficiency to any great extent. Despite these limiting factor, it has been possible to develop submersible motor pumps which represent an economic alternative solution to conventional pumps, and have fairly good efficiencies.

The submersible motor is rigidly coupled to the pump. There are three different basic types of motors in existence today.

4.1.1 OIL-FILLED SUBMERSIBLE MOTORS

It is necessary for this type of motor to be fitted with a completely reliable and leakproof shaft seal. The dissipation of the waste heat generated by the motor (as a result of the relatively low thermal conductivity of oils), and thermal expansion present problems which require correspondingly expensive solutions. In addition, oil has the disadvantage of a higher fluid friction than water, but on the other hand it permits the use of antifriction bearings.

4.1.2 SEMI-WET SUBMERSIBLE MOTORS

In this design of motor, the stator compartment and the winding are sealed off from the water-filled rotor compartment by a can. To improve heat dissipation, the winding is provided with a cast resin jacket. This type of submersible motor is generally adopted for low rating only ap to approximately 30Kw.

4.1.3 WET OR WATER-FILLED SUBMERSIBLE MOTORS

Whereas developments in the U.S.A. were mainly concerned with oil-filled submersible motors, in Europe the development concentrated its efforts on the water-filled motor. This type of motor is completely filled with water, i.e. the winding is immersed in water, and the plain bearings are water-lubricated (see Figs. 8 and 9).

Quite exceptional increases in output, combined with the practical demonstration of the operational reliability of water-filled motor during the past 20 years point to this type of motor as being representative of future trends. Motors with rating of 1800 Kw have now been operating successfully for several years, and ratings of more than 1800Kw are today in the development stage. A desicive aspect of these successful developments has been the progress made in this field of water proof and pressure-tight plastic insulating materials for winding wires. There has been a steady and continuing improvement in the quality of the plastic materials concerned (polyvenly chloride and polyethylene) as well as in the processing technology, and as a result present-day winding wire insulations are able to withstand very high electrical, thermal and mechanical loadings.

The supply voltage normally selected for motor ratings up to approximately 300 kW is low tension; for ratings up to 1000 kW it is in 3 KV high tension, and for even higher ratings it is 6 KV.

A 10 kV experimental motor has been in operation for 5 years without any occurance of operating troubles (see Fig.9).

The various fields of application of the submersible motor pump can, as a general rule, be accommodated without having to carry out any major modifications to the design and construction of the motor and pump. Usually it will suffice to effect a simple adaptation to the prevailing operating conditions in each case.

4.2 APPLICATION OF THE SUBMERSIBLE MOTOR PUMP SYSTEM TO DEEP-SEA TECHNOLOGY

Deep sea technology has opened up a new field of application for submersible motor pumps. The first time a submersible motor pump was operated in very deep waters was in 1962, when the French submarine "Archimedes" carried a submersible motor pump with a 20 kW driving motor on board. This machine was of completely standart execution except for the pump bearings , and it operated at depths down to 10.000 m. This experiment demonstrated that the submersible motor pump with a water-filled motor was capable of operating reliably even at very great submerged depths.

There followed a whole series of research and development activities in the field of submersible motor pumps. In particular, the insulation of the winding, which is exposed to the total static water pressure, was investigated in autoclaves. It was proved, amongst other things, that the insulating materials normally used, i.e. polyvinly chloride and polyethylene, are not subject to any deterioration of their insulation resistance even at water pressures as high as 600 bar (33,34,35).

In 1976 developments commenced in connection with a system for conveying manganese nodules from the ocean bed at 5250m depth to the surface (36). The deep sea mining vessel "Sedco 445", a converted drilling vessel, was equipped with a conveying system illustrated diagrammatically in Fig.10.

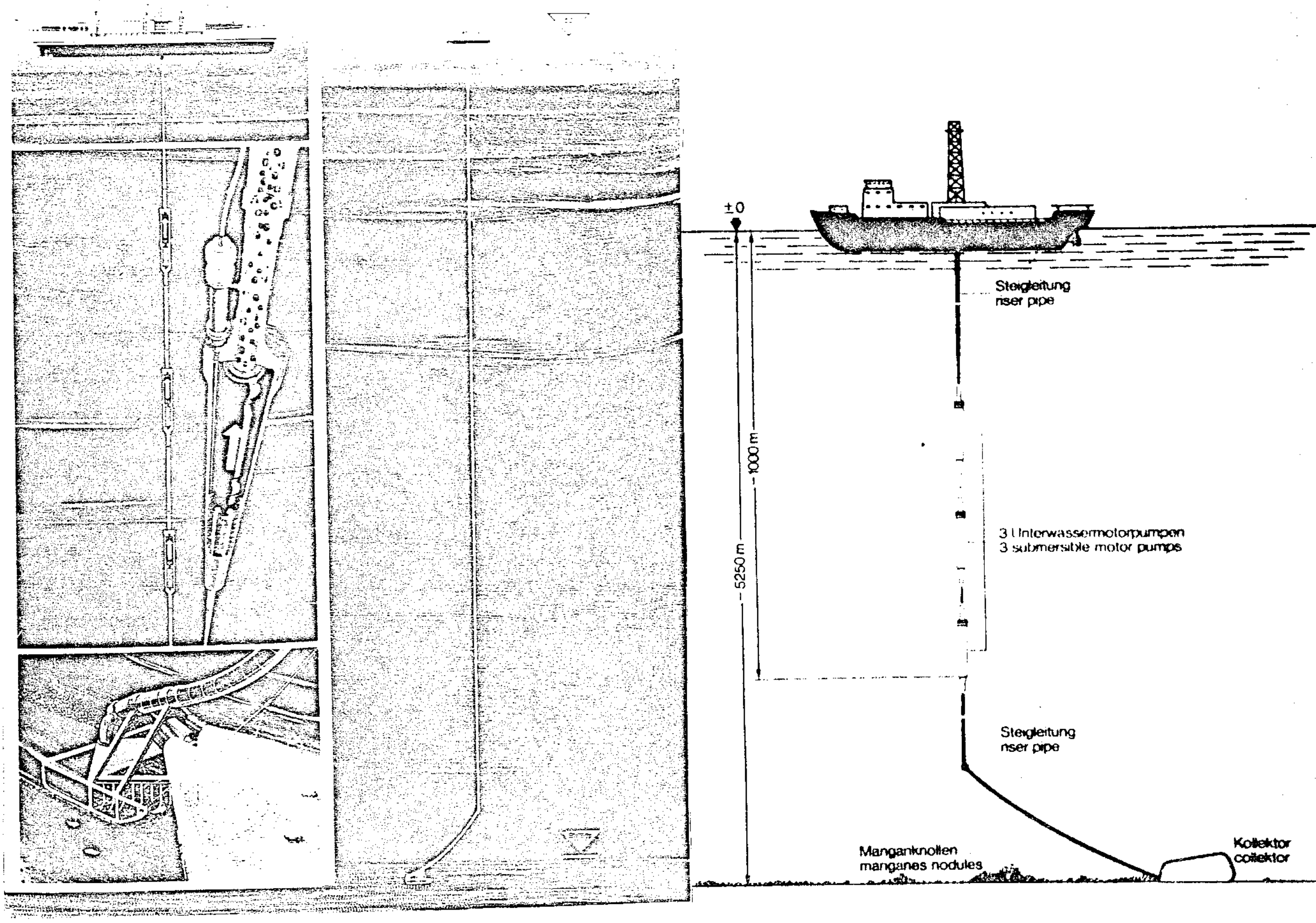


Fig.10 Delivery system for Manganese nodules with submersible motor pumps

An 8" riged pipeline led down from the ship to a level just above the ocean floor. The bottom end of the rising main was connected to the collector on the sea bed by a flexible hose.

The total head generated by the two multistage pumps corresponded to all intents and purposes to the pipe friction losses of the mixture of water and solids in the 5250m long rising main plus a few meters of static head above sea level. The performance data obtained was as follows:

- Capacity Q = 500 m^3/h including 5% solids, i.e. 25 m^3/h solids conveyed.
- Each of the two pumps was designed for a total head of 265m, each pump generated a discharge pressure of 30 bar. The discharge pressure immediately down stream of the second pump was, therefore, 60 bar.
- The driver rating of these two pumps was 800KW each.
- Rotational Speed 1726 RPM at 60 Hz
- Voltage was 4000 V.
- Pump efficiency was 0,75
- Motor efficiency was 0,88

Then, a pre-pilot mining test for metalliferous mud in the "Atlantis II Deep" of the Red-Sea has been undertaken succesfully from 2100meters depth in the March of 1979 by means of a submersible motor pump system (37)

It could be shown that a continuous mining of mud from the deep sea bottom is technically feasible.

CHAPTER III

DESIGN OF A MINING SYSTEM

In accordance with the test mining of metalliferous mud from the Red Sea bottom (38) in the Spring of 1979, the system will be described here could be installed for mining the sediment from the Black Sea bottom.

1. MINING SYSTEM

The mining pipe assembly (Fig.11) having a total length of about 2000 meters, the integrated electric motor driven suctio head, the pump unit and the necessary measuring instruments hang free in the derrick of a drill ship.

As similar to offshore drilling practice the installation of the pipe will be in sections of 27 meters.

Above the vibration screen suction head a measuring sectio with a length of 18 meters will be installed which supports many instruments for measuring and transfer of the mining data by a power data cable to the process computer on the deck of the ship.

In the suction head an underwater electric motor induces a vertical oscillation movement to the conical screen, using a curved disc for transmission of the rotational movement to a vertical oscillation. This vibration screen is to ease efortless penetration into the sediment layers by destroying the physical structure and fluidify the mud. These processes are assisted by the ejection of pressure water, generated in the main pump unit. The sea water descends to the water jet nozzles of the suction head by means of a hose, attached along the pipe string. A spring damping element protects the pipe string against an upward transmission of the vibration.

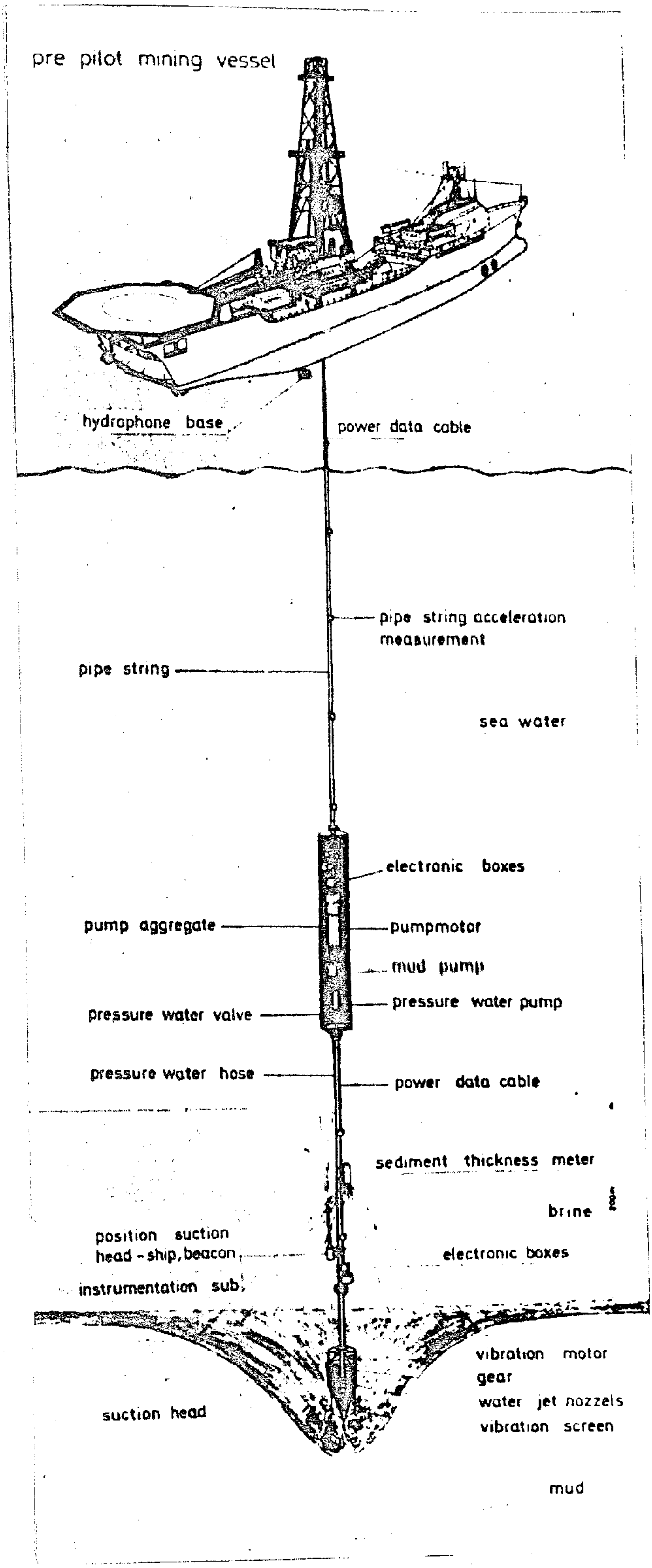


Fig.11 General view of the mining system

The major components of the pump unit are the main mud pump, the electric driver, aflush pump for pumping sea water down to the suction head, the water regulating systems which permit a direct regulation of the water quantity down to the suction head, the electronic control equipment and the distribution and junction boxes, which serves the distribution of the power and the connection of the coax-cable to the data transfer system.

Deep-sea power cable, which also serves for data transmission will be attached alongside the pipe assembly with the water hose from the flush pump down to the suction head and the pipe assembly control system.

The necessary power for the underwater electric motors, the instruments and for some regulation components is fed by a diesel generator package on the deck of the mining ship.

A coaxial cable in the main power cable transmits the signals from all instruments to the surface, after processing digital signals in two electronic boxes above the suction head and in the pump unit. In the control and electronic container these signals are tape-recorded, processed, printed and shown on a display. Using these data the whole mining plant and the generator are controlled and regulated in this container as well as the mining procedure itself.

A radio and telephone contact to the ships'navigation controlcenter allows the observation of the ship's positioning and of the position of the suction head with relation to the vessel. The drift of the suction head resulting from sea currents and ship movements is indicated using a suction head positioning acoustic beacon and a hydrophone base below the vessel.

Many instruments are installed in the system to operate the mining procedure and to detect the mining characteristic data. In the instrument sub directly above the suction head and in the pump station the following data are recorded: inside and outside pressure, pressure losses, temperatures, rotation speed of the pump shaft, pump pressure etc. The movement of the pipe string is measured by 7 separate accelerometers. The distance between the suction head and the sediments as well as the penetration depth into the sea bottom is determined by an acoustic sediment thickness meter. *

The dynamic pressure loss in the pipe, the flow rate, the density of the flow mixture and the solid content could be additionally recorded in a separate 60m pipe section on deck of the vessel. The influence of the sea motion, during the measuring of the dynamic pressure loss should be excluded by a particular arrangement of the pipe system. The complete energy supply of the instruments, the pump motor and the control container is centered in the generator unit on deck in order to be independent of the ship's energy system at any time.

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* This acoustic system was developed by Preussag because the use of a TV camera could not be considered due to the mud plume induced by the section head in action.

2. SPECIAL REQUIREMENTS FOR SUBMERSIBLE MOTOR PUMP FOR THE MINING OF DEEP-SEA SEDIMENTS

If one wishes to use submersible motor pump in deep-sea application, one must then consider the special conditions prevailing in such a submarine plant, e.g.

- The submarine portion of the plant is fully inaccessible
- Therefore, the plant must have an extremely high reliability in operation during a predetermined period of time
- The vertical piping has a length of some kilometers
- There is a high static pressure at the begining of the piping
- The concentration of the solids is not a constant value
- The carrier medium is sea water
- Transverse flows must be anticipated in different depths of the sea
- The system must be capable of traveling along the stratum i.e. it must be of the movable type
- Mounting/assembly work must be carried out using the shipboard appliances.

The pump unit must be arranged so deep below the water surface so that the hydrostatic pressure will be equal to or higher than the suction pressure produced by this system and required for transport, in other words: the immersion depth of the suction pump must be higher than its head. (Since the suction pressure is limited to less than 1 bar, i.e. the atmospheric air pressure prevailing, so that the pump would cavitate).

Even if one deals with clear sea water, considering a sea depth of l=2km and referred to a friction coefficient λ_w=0.02 and a pipe diameter of D = 1m, a rough estimation of this immersion depth yields the following figures

$$T = \lambda_w \cdot L/D \cdot v^2/2g \qquad (1.a)$$

$$= 0.o2 \cdot \frac{2000}{1.0} \cdot \frac{v^2}{2.10} \qquad (1.b)$$

$$= 2v^2$$

where all units are in meters and seconds.

In the case of a transport of mud, ahigher figure will have to be considered for the friction coefficient λ, so that an immersion depth of the pump unit of several hundreds of meters is absolutely realistic.

A pumping station arranged in such a depth of the sea is fully inaccessible during its operating phase. Furthermore, it must be started from the fact that a submarine transport system is working uninterruptedly for as long as the weather factors at sea will allow it. Thus, a very high degree of reliability is required. This requirement is so stringent that all other requirements, also that regarding profitability, must be abondened. Thus, the pumping unit is not permitted to be worn by erosion or corrosion during its operating time of, say, 9-10 months. In addition, it must be considered that the long piping, from the surface of the sea to the bottom of the sea, is always surrounded by the sea water and subjected to all transverse flows; since it must be slowly moved due to the travel of the pick-up device along the bottom of the sea, anchoring means cannot be provided for. Therefore, as little resistance as possible shall be opposed to transverse flows of the sea water, if any. This requires narrowly limited dimensions in horizontal direction, i.e. vertically to the pipe axle; this, simultaneously, facilitates mounting of all submerged components of the plant which, to the experience gained in "off-shore" technology, will probably be mounted section by section from the working platform of a ship and must be lowered through an opening.

As a result, the properties required of the pumping unit are as follows:

- Every wear affecting functioning, especially wear by erosion must be precluded
- The system must not become clogged
- The movable components of the system must be of sturdy design
- There must be remote-control of the plant
- Surges must be avoided
- Faces of resistance opposed to transverse flows must be minimized
- The weight of the complete system must be as low as possible
- The materials must be protected against corrosion

3. MINING OPERATION

A pre-pilot mining test for metalliferous mud in the "Atlantis II Deep" of the Red Sea has been undertaken successfully in the Spring of 1979 (37,38). Mining operation in this case consisted of the following steps.

After lowering the suction head to about 5 meters above the sediment surface, the pump motor is started. The rotation speed of the pump varies by adjusting the frequency of the generator from 48 to 60 cycles. About 60 seconds after starting the pump, nearly stationary mining conditions are observed in the 2200m pipe string. The first brine which was sucked in above the sediments flows out at the pipe outlet on deck after 15-20 minutes having a flow velocity of 1.8 to 2.5 m/s.

The penetration of the suction head into the sediment started in steps of one meteror less. During penetration mud was sucked in from the sediment layers in different depths and pumped to the surface where the varying colours of the layers could be observed with ease. This procedure made the penetration of the suction head to a depth of 18 meters, in any case to the hard anhydrite layer below the metalliferous sediment, possible.

During many operations different dredging techniques were tested indicating different sediment characteristics in the four mining sites. It could be shown that it was possible to ditch trenches closely side by side with different penetration depths of the suction head. During this procedure the suction head was moved forward continuously by means of the slow speed of the ship. Additionally a square area had been ditched down to the anhydrite layer, mining the sediment layers in several penetration steps of about 3 meters each.

The property of the sediments and the mining behaviour of the mud, respectively, is variable in this 60m^2 area of the mineral deposit. Therefore, it can be concluded that a mining system for a commercial plant of longer life time must have a wide working range in order to be able to mine deposits with varying sediment properties.

The dynamic pressure loss in the pipe and the efficiency of the pump showed oscillatory behaviour during mining. This effect must be considered and must be regulated by using different pump rotation speeds.

4. SPECIAL TECHNICAL PROBLEMS

Many technical problems arise when testing a prototype for the first time, especially in offshore operation. One of the most difficult problems in Red Sea application was the sealing of suction head at the tappets which moved the vibration screen. Brine leaked into the oil-filled driving housing and led to some corrosion and electrical problems which could not be solved without a completely new design. Additionally, an oil leak at the pump bearings was found. These bearings are installed outside the pump housing without any contact to the flow mixture with the micro-grained mud. They ran in separate oil-filled housings surrounded by sea water only. This technical problem could be solved with a newly developed oil-water pressure compensation unit.

Contrary to the earlier reservation the data and power cable connections in the silicon oil-filled junction boxes worked without fault.

CHAPTER IV

APPLICATION OF SUBMERSIBLE MOTOR PUMPS FOR MINING THE BLACK SEA SEDIMENTS

1. CALCULATION OF ENERGY REQUIREMENTS FOR THE PUMPING PROCESS

The operation involves pumping of sediments from a depth of 2000 meters having the consistency of mud in the form of sea water with the flow rate of 2 m^3/s and with 9% concentration of solid particles that have a density of 2500 kg/m^3.

Based on the above mentioned operation data, following formulation is established to calculate the power requirements for pumping system.

If $\dot{V}$ is accepted as the volumetric flow rate of sediments, mass flow of sediments is given by

$$\dot{M}_s = \frac{\dot{V}_s}{\rho_s} \qquad (2)$$

and

$$\dot{V}_s = \dot{V}_{Tot} \times C_T \qquad (3)$$

where V_{Tot} is the total volumetric flow rate and equals to $2m^3/s$,

C_T is the transport concentration by volume and equals to 0.

ρ_s is the density of sediments and equals to 2500 kg/m^3.

Since total volume flow is the sum of volume flow of water and volume flow of sediments, eq. (3) can be written as

$$\dot{V}_s = (\dot{V}_s + \dot{V}_w) \times C_T \qquad (3a)$$

where $\dot{V}_w$ denotes volume flow of water, or

$$\dot{V}_w = \dot{V}_s(1/C_T - 1) \qquad (3b)$$

Then, in order to find the velocity of water in the pipe, following formulation can be utilized

$$v_w = \frac{\text{Total volume flow}}{\text{Cross sectional area of the pipe}}$$

$$= \dot{V}_{Tot}/S \qquad \text{or} \qquad (4)$$

since $S = \pi D^2/4$ (5)

where D is the diameter of the pipe, eq. (4) becomes

$$v_w = \frac{4\dot{V}_{Tot}}{\pi D^2} \qquad (4a)$$

where v_w is the velocity of water.

Since settling velocity of sediments is small compared to v_w, velocity of sediments can be taken as

$$v_w = v_s$$

For calculation of pressure losses in the pipe, following formulation is used (39,40,41)

$$\Delta p = (\lambda_w + \mu\lambda_s)\ \frac{L}{D} \cdot \frac{\rho_w}{2} \cdot v_w^2\ (1-C_T) \qquad (6a)$$

or denoting $\lambda_w + u\lambda_s$ by λ_{Tot}, eq.(6a) becomes

$$\Delta p = \lambda_{tot}\ \frac{L}{D} \cdot \frac{\rho_w}{2} \cdot v_w^2\ (1-C_T) \qquad (6b)$$

where Δp total pressure loss,

ρ_w density of sea water(1o25 kg/m3 for Black Sea)

L total pipe length

λ_w friction coefficient for water and equals to 0.02,

λ_s friction coefficient for sediment,

λ_{tot} total friction coefficient

μ mixing proportion considering the effect of weight and is given by

$$\mu = \frac{\dot{\mu}_s}{\dot{\mu}_w} \qquad (7)$$

where u_w is the mass flow rate of water, or

$$\mu = \frac{\dot{V}_s x \rho_s}{\dot{V}_w x \rho_w} \qquad (7a)$$

Friction coefficient of sediments is calculated by (41)

$$\lambda_s = 0.004 + \frac{2}{Fr}\frac{\rho_s-\rho_w}{\rho_s} \qquad (8)$$

where Fr is the Freude's number and is given by

$$Fr = \frac{V_w^2}{Dg} \qquad (9)$$

here, g is the acceleration of gravity.

The shaft input of the submersible motor pumps is calculated a

$$N = \frac{V_{tot} x \Delta_p}{\eta_m x \eta_p} \qquad (10)$$

where η_m is the efficiency of submersible motor,

η_p is the efficiency of submersible pump

Finally, total head should be supplied by the submersible pump is given by

$$H = \frac{\Delta p}{g \cdot \rho_w} \qquad (11)$$

Using the above formulation, necessary shaft inputs are calculated for pre-selected pipe diameters. The results of calculation are given in table 4.

According to the results of above calculation, it is recommended to select the pipe of 1.13 meter diameter. In this case, minimum immersion depth, by using o eq. (1) in section III.2, should be

$$T = 0.8116 \frac{2000}{1.13} \cdot \frac{2^2}{2x9.81}$$

$$= 293 \text{ meters}$$

4 Results of the calculations based on 9% concentration with $2\ m^3/s$ flow rate and zero settling velocity of sediments

iption	Notation		Quantity		Units
flow of sediments	$\dot{M}_s$		450		kg/s
of the sea	L		2000		m
ty of sediments	ρ_s		2500		kg/m^3
ty of sea water	ρ_w		1025		kg/m^3
port concentration by volume	C_T		0.09		-
e flow of sediments	$\dot{V}_s$		0.18		m^3/s
e flow of water	$\dot{V}_w$		1.82		m^3/s
volume flow	$\dot{V}_{tot}$		2.0		m^3/s
iency of pump	η_P		0.75		-
iency of motor	η_m		0.80		-
g proportion	μ		0.2412		-
ion coefficient for water	λ_w		0.02		-
diameter	D	0.8	0.92	1.13	m
ity of water	v_w	4.0	3.0	2.0	m/s
ity of sediment	v_s	4.0	3.0	2.0	m/s
e's number	Fr	2.039	1.0	0.36	-
ion coefficient for sediment	λ_s	0.581	1.184	3.2818	-
friction coefficient	λ	0.160	0.306	0.8116	-
sure loss	Δp	29.85	27.92	26.8	Bar
Head	H	296.8	277.6	266.5	m
absorbed on shaft	N	9948	9305	8932	kW

In order to allow for an adequate safety margin, a submerged epth of 300-310 meters can be used.

Also, submersible pump should be selected as regards the vailable motor size. Hence to meet the above-mentioned reflections, hree-pumps in parallel should be used with the characteristics pecified below:

Capacity of each pump	$Q = 2400\ m^3/h$
Head	$H = 266.5$ meter
Max. power of each pump	$N_{max} = 3.25$ MW
Speed	$n = 1450$ R.P.M.
Frequency	$f = 50$ Hz
Voltage	$V = 6$ kV
Max. diameter of the system	0.8 meter
Length of the submersible motor pump	7.6 meter
Total weight of the motor pumps	13700 kg

The last three items of the data are for BPK 647/4a type KSB ade pump and MLAQV 325-605 type motor (42) .

. MATERIAL COMPOSITION OF THE PUMPING EQUIPMENT

According to the special requirements in respect of resistance f the pump materials to corrosion by sea water and minimizing abrasive ear, following material composition could be recommended for submer-ble motor pumps (43).

Impellers, diffusers, connection pieces, pump and motor casing:

Noridur 9.4460 (see table 5)

Pump shaft and stator cover: Stainless steel 1.4462

Bearing bushes, bearings, impeller and case wear rings in pump:

Hardened stainless steel

Bearing bushes and bearings in motor: Carbon/chrome steel

Mechanical seal: Silisium carbide

C_{max}	Mn_{max}	Si_{max}	Cr	Ni	Cu	N_2
0.04	1.5	1.5	24-26.5	2-2.75	2.75-3.5	Balanced

Table 5. Chemical composition of Noridur 9.4460

3. TRANSPORTATION OF THE SEDIMENTS

In order to transport the sediment+ water mixture, there are two available methods.

3.1 TRANSPORT BY FLOATING PIPE-LINES

Since the pipeline to transport sediment + water mixture should be of mobile type, transportation by floating pipe-lines could be considered. The material of pipes may be plactic. Also, a number of pumping stations must be installed. Each pumping station could create a 10 bar pressure difference, at least.

The main disadvantage of this system is the susceptibility to surface conditions and marine traffic. In case of failure for any reason, all system should be shut down (44,45,46).

3.2 TRANSPORT BY SHIPS

Approximately, 175.000 m^3 mixture of which 9% is solid should be transported to the coast per day. In order to meet this requirement two ships are required, each having the 175000 m^3 capacity, which will be run in turn.

The capacity of transportation ships can be reduced, if the mixture is concentrated by means of a known concentration processes. On this respect filtration seems to be the first easy operation in order to get rid of the brine as much as possible(47

4. FLOTATION

For a commercial scale mining operation it may not be feasible to ship the mined flow mixture to the shore without any preliminary effort in increasing the uranium concentration of the sediment. In that case, several tankers would be necessary for the transport in order to cope with the projected mining rate of about 190.000 tons per day. The separation of the water from the mixture (91% brine) by sedimentation is difficult because of the very slow settling velocity (=2-7 cm/h) of the micro-grained solids. Grain size of the sediments is in the range of 3-5 μm . This grain-size of sediments does not even allow the use of centrifugal separators.

Another process to decrease the volume and to increase the sediment contents for the subsequent treatment is flotation. After mining and storing of mud in the ship tanks, it is pumped into the flotation plant, modified for application under sea-going conditions.

The flotation process is based on the property that air introduced into the flotation cells attracts the U_3O_8 compounds in the presence of so-called flotation reagents. The air bubbles rise to the surface of the flotation cells where concentrate foam can be skimmed off (47).

5. DISPOSAL OF TAILINGS

The residue of the flotation (tailings) representing predominently the non-metalliferous components of the mined mud can be disposed at a depth of 400-500 meters through a disposal pipe at the bow of mining ship.

In Red Sea application, the tailing plume was followed and monitored to investigate its drifting and settling behaviour. It was noted that the discharged tailings settle to a depth of about 1200 meters in a very short time, probably as a result of jet flow and the force of gravity.

6. COST ANALYSIS

Energy requirement for mining of 1 m^3 mixture (91% brine + 9% sediment) can be calculated as follows:

On the basis of 7 ppm average U_3O_8 concentration in the mined ash after combustion, sediment flow rate of 450 kg per second (450x3600 =1.620.000 kg wet sediment per hour or 1.620.000x0.2 = 324.000 kg dry sediment per hour after combustion) will result 2.27 kg U_3O_8/hour. Assuming 270 days of operation period annually, total U_3O_8 quantity will be 2.27x 24 x 270 = 14.7 tons per year.

In order to obtain above figure:

1.620.000 x 24 x 270 = 10.5 x 10^9 kg wet sediment has to be mined annually by weight or 4.2 x 10^6 m^3 by volume.

This also equals to 4.2 x 10^6 m^2 or 4.2 km^2 area, since U_3O_8 is located in upper 1 meter strata of the Black Sea basin.

Considering a suction efficiency of 80% and a sweep efficiency of 70%, (Sweep efficiency is a function of the characteristics of the mining, navigating and ship's operating systems. The suction head is suspended 2 km beneath the ship, which is subject to the combined effects of currents, winds, swells, and waves. Even if the systems involved offered the precision needed to sweep an area ecological considerations demand that a large percentage of the Black Sea floor be left undisturbed. Examinations of the capabilities of canditate mining systems imply that sweep efficiencies of 45 to 75 percent can be expected (23). In other words, 25 to 55 percent of the workable sea bottom will remain in its pristine state) total area to be mined in a year should be

$$\frac{4.2}{0.7x0.8} = 7.5 \text{ km}^2$$

If project life is planned as 25 years, area to be mined seems to be 187.5 km^2 and as a result 367.5 tons U_3O_8 can be obtained. Its market value will be approximately 32.37 million U.S ∅ over 88 ∅/kg.

Furthermore, since total flow rate is 2 cu.m. per second or 46.6 million cu.m. per year, energy requirement for mining 1 cu.m mixture is calculated by

$$E = \frac{N.t}{G_{s}} \qquad (12)$$

Where t is the operation period by hours per year

G_s is the total flow rate by cu.m per year

N is the input power of submersible motor pump.

then (see section IV.1)

$$E = \frac{9750x6480}{46.656.000}$$

$$= 1.354 \text{ kwh/1m}^3 \text{ mixture}$$

Since $1m^3$ mixture contains 0.09 m^3 wet sediment or 0.09 x 2500 = 225 kg wet by weight and after combustion. 225 x 0.2 = 45 kg dry by weight, then uranium quantity of $1m^3$ mixture will be 0.045(ton) x 7 (gr/ton) = 0.315 gr, since 1 ton dry ash contains 7 gr U_3O_8 as an average.

The value of 1 m^3 mixture will, therefore, be

$0.315 \times 10^{-3} x 88 = 0.0278$ ∅ or 4.16 TL (assuming 1∅=150TL)

As it is easily seen from above calculation that energy cost alone, on the basis of 10TL/kwh energy price, comes out to be three times (13.54/4.16) higher than the U_3O_8 price to be obtained from $1m^3$ mixture. Also, on preliminiary estimations, submersible motor pumps cost approximately DM 1.2 million (42) and piping of 2000 meters length needs $ 278.000 if its material is carbon steel having a wall thickness of 8 mm. Comparative analysis of piping system is given in table 6.

Wall Thickness(mm)	Material		Weight(tons)
k	Carbon steel	316 SS	W
7.1	250.000	1.600.000	356
8.0	278.000	1.780.000	396
8.8	306.000	1.960.000	436
10.0	348.000	2.230.000	496

Table 6. Piping system costs with 1.13 meter diameter in US $

Besides above costs, other costs are, also, considered over installation and the yearly operation charges, i.e. procurement and reconstruction of a mining ship and two transportation ships, establishment of the installations for flotation, drying, lyeing and yellow cake production (3,48) interest and depretiation time, personal, maintenance, charter of two tank ships, operational material.

CHAPTER V

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

A comperative study of available deep-sea mining techniques was made and that with submersible motor pumps was dwelled on with the aim to apply this system for mining the uranium contained in Black Sea sediments.

Progress in the field of deep-sea technology is dependent on many factors. The submersible motor pump has already made a substantial contribution in this respect. The water-filled submersible motor appears to be the most suitable form of under water driver because of its design and concept, particularly for operation at great depths of immersion. Also outputs up to 5000 kW and voltages of 10.000 V are anticipated in the near future . Since the mining cost of 1 m^3 mixture is 1-2 US ∅ according to the Red Sea application results (49), the uranium concentration in Black Sea sediments should be almost 250 g per ton ash, an the basis of 1∅/m^3 mining cost and 88 ∅/kg U_3O_8 market price, or in order to be able to meet the energy cost alone concentration should be 21.5 ppm. These figures show that mining of the sediment is not economically significant now, but

a) The situation may change in the years to come should the global demand for uranium grow beyond the present expectations

b) By-products produced from the organic portion of the sediment could support the uranium price.

In order to minimize the transportation costs, flotation process seems to be needed to increase the sediment contents in

the mixture. For further study, particle size distribution and reagents to hold the U_3O_8 particles should be investigated.
As a result, mining of Black Sea sediments by the use of submersible motor pumps is technically feasible, however, it will not be on economical one.
Furthermore, such a system can be utilised in other deep-sea processes i.e cleaning of Golden Horn.

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