53192

Distr.
Limited

E/CN.14/EP/INF/13
5 December 1973

Original: ENGLISH

UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC COMMISSION FOR AFRICA

Regional Conference on Petroleum Industry
and Manpower Requirements in the Field of Hydrocarbons

Tripoli, 2-12 February 1974

THE LAKE KIVU METHANE - PROBLEMS OF EXTRACTION AND THEIR MATHEMATICAL-PHYSICAL STUDY

Document prepared by K. Tietze

Bundesanstalt fur Bodenforschung
(Geological Survey of the Federal Republic of Germany)
(West Germany Delegation)

INTRODUCTION

In the deep water of Lake Kivu (maximum depth c. 500 m, size c. 50 x 100 km, situated between the States of Zaïre and Rwanda), after Schmitz and Kufferath 1)(1955), nearly 45 x $10^9 m_n^{3*}$ of methane and three times this quantity of carbon dioxide are physically dissolved owing to the water pressure.

The fact that this occurrence exists at all in Lake Kivu is attributed to an adequate density increase between 250 to 300 m depth which leads to a separation of the gas-bearing deep water from the gas-free surface water 1) Convective motions in the upper water layer only reach down to this "boundary layer", so that the deep water is kept in the lower layer.

---

* m_n^3: Under normal conditions, pressure 1013 mbar, temperature $0^\circ C$.

Economic use of the methane occurrence

At present there is a comparatively small production station on Lake Kivu with a capacity of about 4,500 m_n^3 of methane/d (Union Chimique Belge 2), 1962). In a technical-economic feasibility study (Preussag 3), 1972) considerably bigger production stations with capacities of up to about 200,000 m_n^3 of methane/d are dealth with. The industrial use of such quantities in the Kivu region seems practicable in the intermediate run (Deutsches Institut fur Afrikaforschung 4), 1973). Further details cf. Conference paper by H. Boigk.

Theoretical studies of a large-scale production

For the production of 200,000 m_n^3 of methane/d about 700,000 m^3 water/d must be extracted and after degasification returned into the lake without damage to the occurrence. Before starting production on such a large scale, theoretical studies should first be made for the best possible way of extraction from this unique occurrence. To avoid a reduction of the stability of stratification (stability $E = (1/\rho).d\rho/dz$; ρ= density, z = depth coordinate), the extraction must not be carried out haphazardly, and neither must the large quantities of water be returned into the lake at random. Otherwise, the gas-bearing deep water would more easily be affected by the convective motions in the upper water layer, and gas-bearing water would thus be lost. To this end, studies must be carried out on:-

How far the stability of stratification is reduced by turbulent mixture and induced convection in case of various production techniques;

How the conveying tubes are approached;

How the degasified water spreads within the lake, and

How the stratification is affected by these processes in the long run.

Such studies have not been made so far.

To assess the impact of such a physical interference caused by the large-scale production from the occurrence, the resultant flow conditions must be computed. In lakes and in the oceans, the water motions are in general turbulent[5)], as here, after Reynold's criterion, laminar currents change into turbulunce even at very low velocities. The flow velocity $\vec{v}(t)$ (t = time) may be given as the sum of a mean velocity $\vec{v}_m$ and an additional turbulent velocity $\vec{v}_t(t)$ varying statistically with time. The degree of turbulence is dependent upon the stability of stratification. With the help of Richardson's number including the stability of stratification and the gradient of the mean flow velocity, the range of turbulence can be given. The mean flow velocity $\vec{v}_m$ can be computed from the Navier-Stokes equations if instead of the molecular viscosity coefficient, the turbulent exchange coefficients (including eddy viscosity, eddy diffusivity, and eddy heat conductivity) are used. However, the exchange coefficients are not material constants but depend upon he state of motion of the water ! Neglecting the Coriolis term and assuming a constant horizontal exchange coefficient for the quasi-station ary case, the Navier-Stokes equations for an incompressible fluid (possible simplification for water) are[5)]:-

$$(\vec{v}_m \cdot \nabla)\, \vec{v}_m + \frac{1}{\rho} \nabla p - \frac{A_h}{\rho} \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) \vec{v}_m - \frac{1}{\rho} \frac{\partial}{\partial z} \left(A_v \frac{\partial v_m}{\partial z} \right) = \vec{K}$$

$$\nabla \vec{v}_m = \frac{1}{\rho} \left\{ - \sum_{n=1}^{N_1} \delta(z - z_n)\, S_n + \sum_{\nu=1}^{N_2} \delta(z - z_\nu)\, Q_\nu \right\}$$

$$\rho = \rho(x,y,z)$$

where x, y, z = carthesian coordinates, ∇ = vector operator

$= \frac{\partial}{\partial x} \vec{i} + \frac{\partial}{\partial y} \vec{j} + \frac{\partial}{\partial z} \vec{k}$, $\vec{i}, \vec{j}, \vec{k}$ = unit vectors in x, y or z-direction, p= pressure, A_h = horizontal exchange coefficient,

A_v = vertical exchange coefficient, $\vec{K}$ = external forces (e.g. gravity)m S = sink (extraction), Q = source (return) (in this case only sinks and sources on the z-axis are considered), N_1, N_2 = number of sinks and sources, respectively,

δ δ-function = 0 for $z_n \neq z$, ρ = density
1 for $z_n = z$

Mathematically, the problem concerned here must be dealth with in the following way:-

First, the waters of Lake Kivu are assumed without a natural motion. Putting $A_h = A_v = \eta$, the above partial differential equation system is solved numerically with a finite difference approximation method after some further neglects (an analytical solution is not possible owing to non-linearity). Thus, a certain flow pattern is obtained which always depends upon how the sources and sinks are arranged. With the help of the calculated velocity gradients the exchange coefficients are then estimated, and with these values for A_h and A_v the equations are again solved. This process is repeated until there is no longer any considerable change in the flow pattern. At the same time, the width of the turbulent layers mixed by extraction and by return of the water is determined with the stability formula and Richardson's number. After these computations have been completed, approximate solutions are at hand for the flows caused in the lake. Thus a computation is available of the impact on Lake Kivu merely by production. But neither is the water of the lake stationary in the upper main layer (seasonal convection, wind stress), nor is this the case in the lower main layer (convection is caused simultaneously in the lower layer by convection in the upper layer, influx on the lake bottom 6) internal waves in the boundary layer 7) Measuring the flow conditions in the lake would be too expensive, and therefore it must be tried to assume water motions in the lake on the basis of the measurements made for the above computations. The computations are then repeated using the estimated total exchange coefficients.

Measurements planned on Lake Kivu

In the course of a project planned for the summer of 1973 on Lake Kivu, the data required for the computations just explained are going to be recorded, as at present there are not sufficient data at hand. Very exact measurements are planned with a submarine probe to determine the in-situ density, temperature, electrical conductivity, and pressure. To this end, vertical profiles, systematically spread over the lake, have to be recorded. In this way, also horizontal profiles are obtained. In addition, the measurements will be made in the boundary layer as a function of time. In particular, the in-situ density profiles are of importance for the calculation of the stability, the solution of the Navier-Stokes equations, the determination of the turbulence range and the exchange coefficients, the calculation of internal waves, and the estimation of the natural water motions. Measurements of this kind have not been made in Lake Kivu so far. As the traditional submarine probes operating in an indirect way are hardly suited for the density determination owing to the high gas content in the Lake Kivu water, a special submarine probe has been developed. With this probe, the in-situ density can be measured in a direct way with an accuracy of $\pm 2 \cdot 10^{-5}$ g/cm^3.

It is planned to take water samples at various depths in certain horizons of the places where measurements were made with the submarine probe, to take them on board under in-situ pressure, and to degasify and investigate them there. It was already in 1955 that Schmitz and Kufferath$^{1)}$ measured gas samples, but the results deviate by about 25 per cent from a new profile by Degens et al.$^{6)}$ (difference of depth position of the samples in one profile: 25 m to 50 m). Before laying out the production stations, the methane and carbon dioxide content of the water drawn in must be known more accurately. The samples to be taken on the basis of the measurements with the submarine probe must also be more closely spaced. This is to determine which gradients of the methane-carbon dioxide - water ratio correspond to certain density, conductivity and temperature gradients in the boundary layers. In addition, the degasification behaviour (PV-diagram) is going to be analysed on samples of one profile, and the compressibility of the gas-bearing and degasified water will be determined.

Furthermore, the sample material will be used for $^{12}C/^{13}C$ isotope analyses to support statements on the origin of the gas 6), and for ^{14}C age determinations to determine the residence time of the deep water in certain horizons. For a comparison with the ^{14}C data, it could be tried to compute the residence time from the measurements with the submarine probe.

The theoretical analyses and the measurements recommended in this paper are meant to provide a reasonable concept of how to extract the Kivu methane on a large scale. It must be tried to avoid, from the very beginning, any risks of affecting the stability of the occurrence which would lead to an unprofitable production.

Acknowledgements

Thanks are due to Prof. Dr. Boigk and Prof. Dr. Durbaum for supporting these studies. The financial means required were granted by the Ministry for Economic Co-operation of the Federal Republic of Germany.

Selected References

1) D.M. Schmitz und J. Kufferath: "Problèmes posés par la présence de gaz dissous dans les eaux profondes du lac Kivu", Académie Royale des Sciences Coloniales, Bulletin des séances, nouvelle serie 1, 326 (1955).

2) Union Chimique Belge: "Gaz du Kivu", Rapport des Recherches (1954); "Rapport de la mission Gaz du Kivu" (1959); "Gaz du Lac Kivu", Rapport de la mission confiée à UCB par l'organisation des Nations Unies pour le développement industriel (1971), Bruxelles, unpublished manuscripts.

3) Preussag: "Technisch Vorstudie - Forderung und Aufbereitung des im Kivu-See gelösten Methans", Technische Hilfe der Bundesrepublik Deutschland, Hannover (1972), unpublished.

4) J.P. BreitengroB: "Vorläufiger Ergeb nisbericht zur Frage der wirtschaftlichen Nutzung des Kivu-Methangases", Deutsches Institut fur Afrikaforschung, Hamburg (1972), unpublished.

5) W. Krauss: "Methoden und Ergebnisse der Theoretischen Ozeanographie", Bd. 1, 2, 3, Gbr. Borntraeger-Verlag, Berlin-Nikolassee 1966.

6) E.T. Degens, R.P. von Herzen, How-Kin Wong, W.G. Deuser and H.W. Jannasch: "Lake Kivu: Structure, Chemistry and Biology of an East African Rift Lake", Geologische Rundschau, 62, 245 (1973).

- - - - - -