UNCLASSIFIED

AD 453362

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

CATALOGED BY DDC
AS AD No. 453362

HEADQUARTERS QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, US ARMY
Quartermaster Research and Engineering Center
Natick, Massachusetts

CHEMICALS AND PLASTICS DIVISION

Microbiological Deterioration Series Report No. 5

THE MICROBIOLOGICAL DETERIORATION OF HYDROCARBONS AND THE RELATED DEGRADATION OF EQUIPMENT USED FOR THE STORAGE, DISTRIBUTION AND HANDLING OF PETROLEUM PRODUCTS

A SELECTED BIBLIOGRAPHY

by

Donald O. Birkholz
Morris R. Rogers
and
Arthur M. Kaplan

Fungicides and Germicides Branch

DDC
DEC 31 1964
TORRA A

453362

Project Reference:
7-65-01-003

June 1961

DDC AVAILABILITY NOTICE:
QUALIFIED REQUESTORS MAY OBTAIN
COPIES OF THIS REPORT FROM DDC.

CONTENTS

		Page
I.	Microbiological Deterioration of Hydrocarbons and Related Organic Compounds	1
II.	Microbiological Problems Involving Storage and Use of Fuels	5
III.	Microbiological Deterioration and Related Corrosion Problems in Industry	7
	A. Petroleum Production and Refining	7
	B. Metal-Cutting Fluids	8
	C. Miscellaneous	10
IV.	The Relationship Between Sulphate-Reducing Bacteria and Corrosion	11
V.	Progress in the Inhibition of Microbially Induced Deterioration and Corrosion	14
VI.	Laboratory Procedures Used In Petroleum Microbiology	17

THE MICROBIOLOGICAL DETERIORATION OF HYDROCARBONS AND THE RELATED DEGRADATION OF EQUIPMENT USED FOR THE STORAGE, DISTRIBUTION AND HANDLING OF PETROLEUM PRODUCTS

I Microbiological Deterioration of Hydrocarbons and Related Organic Compounds

1. Bakanauskas, Sam, "Bacterial Activity in JP-4 Fuel", WADC Tech. Report 58-32, ASTIA Document No. 151034, 1958.

2. Bakanauskas, Sam, "Bacterial Activity in JP-4 Fuel Storage Tanks", USAF Tech. Memo. 57-2, Supp. 2, WCRT, 1957.

3. Beerstecher, Ernest, Jr., "Petroleum Microbiology", Elsevier Press. Inc., New York, N. Y., 1954.

4. Bennett, E. O., "The Deterioration of Petroleum Products by Bacteria", Proc. 45th Annual Meeting of Chem. Specialties Mfrs. Assoc., pp. 115-120, Dec. 8-10, 1958.

5. Bonetti, Elio M., "Microbiological Research on Oil-Bearing Soils and Microbial Oxidation of Hydrocarbons. (Note 2)", (In Italian), Ricerca Sci. 26:779-802, March, 1956.

6. Bushnell, L. D. and Haas, H. F., "The Utilization of Certain Hydrocarbons by Microorganisms", J. Bacteriol. 41:653-673, 1941.

7. Cribbins, Lois R., "The Bacterial Oxidation of Aliphatic Hydrocarbons", Bull. University of Pittsburgh, Pittsburgh, Pa., 45(8):31-34, 1949.

8. Davis, J. B., "Microbial Decomposition of Hydrocarbons", Ind. Eng. Chem., 48:1444-1448, 1956.

9. Davis, J. B. (Rittenberg, S.C. and Andreoli, A. J.), Symposium on Petroleum Microbiology, Bacteriol. Rev., 20:261-264, 1956.

10. Degray, R. J. and Killian, L. N., "Bacterial Contamination of Refined Petroleum Products", Presented at 9th Conference on Prevention of Microbiological Deterioration of Military Materiel, QM R&E Command, Natick, Mass., Nov. 15-17, 1960.

11. Degray, R. J. and Killian, L. N., "Bacterial Slime and Corrosion in Petroleum Product Storage", Ind. Eng. Chem., 52:74-76, Dec., 1960.

12. Delwiche, C. C., "Biological Transformations of Nitrogen Compounds", Ind. Eng. Chem., 48(9):1421-1427, Sept., 1956.

13. Dostalek, Milan, Staud, Miloslav and Rozypalova, Alena, "The Effect of Micro-Organisms on Petroleum Hydrocarbons", (In Czech), Ceskoslov. Mikrobiol., 2:43-48, 1957.

14. Ekzertsev, V. A., "A Study of Oil Decomposition by Microorganisms Under Anaerobic Conditions", (In Russian), Mikrobiologiya, 27(5):626-633, 1958.

15. Evans, W. C., et al, "Chemistry of the Oxidative Metabolism of Certain Aromatic Compounds by Microorganisms", Nature, 168:772-775, 1951.

16. Fernley, H. N. and Evans, W. C., "Oxidative Metabolism of Polycyclic Hydrocarbons by Soil Pseudomonads", Nature, 182:373-375, 1958.

17. Garnett, J. E., "Growth of Iron Bacteria in Crude Tar", Nature, 185:942-943, 1960.

18. Greathouse, Glenn A., Wessel, Carl J. and Shirk, Harold G., "Microbiological Deterioration of Manufactured Materials", Ann. Rev. Microbiol., 5:333-358, 1951.

19. Haas, H. F., "The Bacterial Utilization of Petroleum Products and the Production of Carotenoid Pigments", Thesis, Kansas State College, Manhattan, Kansas, 1942.

20. Haas, H. F., Yantzi, M. F. and Bushnell, L. D., "Microbial Utilization of Hydrocarbons", Trans. Kansas Acad. Sci., 44:169-177, 1942.

21. Johnson, F. H., Goodale, W. T. and Turkevich, J., "The Bacterial Oxidation of Hydrocarbons" , J. Cellular and Comp. Physiol., 19(2):163-172, 1942.

22. Kapralek, Frantisek, "Assimilation of Hydrocarbons by Microorganisms", (In Czech), Ceskoslov. Biol., 3:82-91, 1954.

23. Knösel, D. and Schwartz, W., "Investigations in Petroleum Bacteriology. II. Occurence of Microorganisms in Petroleum", (In German), Arch. Mikrobiol., 20:362-390, 1954.

24. Kuznetsov, S. I. and Telegina, Z. P., "Some Data on the Physiology of Propane-Oxidizing Bacteria", (In Russian), Mikrobiologiya, 26:513-518, 1957.

25. Ladd, J. N., "The Oxidation of Hydrocarbons by Soil Bacteria.1. Morphological and Biochemical Properties of a Soil Diphtheroid Utilizing Hydrocarbons", Australian J. Biol. Sci., 9:92-104, Feb., 1956.

26. Leadbetter, E. R., "Studies on Some Methane-Utilizing Bacteria", Thesis, University of Texas, Austin, Texas, 1959.

27. Leonard, John M., "Fuel Fungi", Naval Research Reviews, U. S. Naval Research Laboratory, Washington, D. C., Feb., 1960.

28. Luchter, A., "Utilization of Various Hydrocarbons by Bacteria Isolated from Oil-Fields", (In Polish), Acta Microbiol. Polon., 4:271-279, 1955.

29. Margolin, Elias L., "The Biological Deterioration and Degradation of Hydrocarbons", WADC Tech. Report No. 6290, June, 1951.

30. Marr, Eleanor Kirk, "The Bacterial Oxidation of Benzene", Thesis, Pennsylvania State University, 1959.

31. Novelli, G. D. and Zobell, C. E., "Assimilation of Petroleum Hydrocarbons by Sulphate-Reducing Bacteria", J. Bacteriol., 47:447-448, 1944.

32. Obojska, K., "The Breakdown of Saturated and Unsaturated Hydrocarbons by Saprophytic Mycobacteria", (In Polish), Acta Microbiol. Polon., 2:129-132, 1953.

33. Okawaki, M. B., "A Study of Bacteria in Oils", Thesis, University of Nebraska, Lincoln, Neb., 1953.

34. Pomortseva, N. V., "Formation of Organic Acids and Aldehydes by Cultures of Pseudomonas pyocyanea (P. aeruginosa) in Oxidation of Hydrocarbons", (In Russian), Doklady Akad. Nauk S.S.S.R., 117:896-899, 1957.

35. Putilina, N. T., "Microbes Used in Industrial Purification Installations for Removal of Phenols from Waste Water", (In Russian), Mikrobiologiya, 28(5):757-762, 1959.

36. Raymond, R. L., "Oxidation of n-Paraffinic Hydrocarbons", Developments in Industrial Microbiology, Plenum Press, Inc., New York, N. Y., In Press.

37. Razin, S., Gery, I. and Rachrach, U., "The Degradation of Natural Polyamines and Diamines by Bacteria", Biochem. J., 71(3):551-558, 1959.

38. Reese, Elwyn T., Cravetz, Howard and Mandels, Gabriel R., "Activity of Fungi on Oils", Farlowia, 4:409-421, July, 1955.

39. Rosenfeld, William D., "Anaerobic Oxidation of Hydrocarbons by Sulphate-Reducing Bacteria", J. Bacteriol., 54:664-665, 1947.

40. Sharpley, J. M., "Applied Petroleum Microbiology", Buckman Laboratories, Inc., Memphis, Tenn., 1961.

41. Shturm, L. D., "Studies on Hydrocarbon Assimilation by Microorganisms", (In Russian), Mikrobiologiya, 27(6):723-733, 1958.

42. Stanier, R. Y., "The Oxidation of Aromatic Compounds by Fluorescent Pseudomonads", J. Bacteriol., 55:477-494, 1948.

43. Stewart, James E., "Microbial Oxidation of Hydrocarbons", Thesis, Iowa State University, 1958.

44. Stewart, James E., et al, "Bacterial Hydrocarbon Oxidation. I. Oxidation of n-Hexadecane by G-coccus.", J. Bacteriol., 78:441-448, 1959.

45. Stewart, James E. and Kallio, R. E., "Bacterial Hydrocarbon Oxidation. II. Ester Formation from Alkanes", J. Bacteriol., 78:726-730, 1959.

46. Stewart, James E., Finnerty, William R. and Kallio, R. E., "Esters from Bacterial Oxidation of Olefins", Science, 132:1254-1255, Oct., 1960.

47. Stone, R. W., Fenske, M. R. and White, A.G.C., "Bacteria Attacking Petroleum and Oil Fractions", J. Bacteriol., 44:169-178, 1942.

48. Stone, R. W and Zobell, C. E., "Bacterial Aspects of the Origin of Petroleum", Ind. Eng. Chem., 44:2564-2567, Nov., 1952.

49. Strawinsky, R. J., "The Dissimilation of Pure Hydrocarbons by Members of the Genus Pseudomonas", Thesis, Pennsylvania State University, 1943.

50. Thaysen, A. C., "On the Gas Evolution in Petrol Storage-Tanks Caused by the Activity of Microorganisms", J. Inst. Petrol. Technologists, 25:111-115, 1939.

51. Zobell, C. E., "Effect of Bacterial Activity on Petroleum Hydrocarbons", J. Bacteriol., 49:522, 1945.

52. Zobell, C. E., "The Role of Bacteria in the Formation and Transformation of Petroleum Hydrocarbons", Science, 102:364-369, Oct., 1945.

53. Zobell, C. E., "Functions of Bacteria in the Formation and Accumulation of Petroleum", Oil Weekly, Feb. 18, 1946.

54. Zobell, C. E., "Action of Microorganisms on Hydrocarbons", Bacteriol. Rev., 10:1-49, 1946.

55. Zobell, C. E., "Bacterial Release of Oil from Sedimentary Materials", Oil Gas J., Aug. 2, 1947.

56. Zobell, C. E., "Bacterial Activities and the Origin of Oil", World Oil, 130:128-138, June, 1950.

57. Zobell, C. E., "Assimilation of Hydrocarbons by Microorganisms", Advances in Enzymol., 10:443-486, 1950.

58. Zobell, C. E., Grant, C. W. and Hass, H. F., "Marine Microorganisms Which Oxidize Petroleum Hydrocarbons", Bull. Am. Assoc. Petrol. Geologists, 27:1175-1193, 1943.

59. Zobell, C. E. and Morita, Richard Y., "Barophilic Bacteria in Some Deep Sea Sediments", J. Bacteriol. 73:563-568, April, 1957.

60. Zobell, C. E., Sisler, F. D. and Oppenheimer, C. H., "Evidence of Biochemical Heating in Lake Mead Mud", J. Sediment. Petrol., 23 (1):13-17, March, 1953.

II Microbiological Problems Involving Storage and Use of Fuels

61. Allen, F. H., "The Effects of Various Microorganisms on the Precipitation of Lead Tetraethyl from Aviation Fuels and the Formation of Gum in Motor Gasolines", Thesis, University of Texas, Austin, Texas, 1942.

62. Allen, F. H. and Fore, Dan, Jr., "Biological Deterioration of Polysulphide Polymers Employed as Linings for Gasoline Storage Tanks", Ind. Eng. Chem., 45:374-377, Feb., 1953.

63. A. P. I. Bulletin, "The Storage and Handling of Jet Fuels at Airports", A. P. I. Bull. 1503, American Petroleum Institute, N. Y., N. Y., 1958.

64. A. P. I. Bulletin, "Tentative Report on the Use of Plastic Materials for Temporary or Permanent Repairs to Steel Storage Tanks", A. P. I. Bull. 1607, American Petroleum Institute, N. Y., N. Y., 1960.

65. Arthur D. Little, Inc., "Methods of Removing Water from Aviation Fuels", Report to U. S. Navy, Bureau of Aeronautics, Dec., 1958.

66. Boeing Airplane Company, "Investigation of Corrosion and Microbiological Degradation in Integral Fuel Tanks", Document No. D3-3629, Boeing Airplane Company, Wichita Division, Wichita, Kansas, Feb., 1961. (Limited distribution).

67. Boué, J., Ferrier, J. and Louis M., "The Storage Properties of Gasolines in Contact with Water and Tank Wall Materials", (In French), Rev. inst. franc. pétrole et Ann. combustibles liquides, 6:305-311, Aug., 1951.

68. Cowling, J. E., "Inert Linings for Bulk Fuel Storage Tanks", Bulocks Tech. Digest, 61:7-14, Nov., 1955.

69. Deblinger, B., "Research and Development on the Separation of Jet Fuel/Water Emulsions by Means of a Laboratory Mockup Filter/Separator Unit", Material Laboratory Tech. Report, New York Naval Shipyard, Brooklyn, N. Y., Dec., 1959.

70. Henry, James C., "Properties of JP-4 Jet Fuel", WADD TR60-57, Wright-Patterson Air Force Base, Ohio, Jan., 1960.

71. Prince, Alton E., "Microbiological Sludge in Jet Aircraft Fuel", Developments in Industrial Microbiology, Vol. 2, Plenum Press, N. Y., N. Y., In Press.

72. Walterc, E. L., et al, "Practical Test for Estimating Storage Stability of Gasolines", Anal. Chem., 19:987-991, Dec., 1947.

73. Walters, E. L., Minor, H. B. and Yabroff, D. L., "Chemistry of Gum Formation in Cracked Gasoline", Ind. Eng. Chem., 41:1723-1729, Aug., 1949.

74. Watts, H. E., "Explosion in Petroleum Spirit Tank at Saltend, Hull, Yorkshire", His Majesty's Stationery Office, London, 1936.

75. Watts, H. E., "Explosion in Kerosene Tank at Killingholme, Lincolnshire", His Majesty's Stationery Office, London, 1938.

III Microbiological Deterioration and Related Corrosion Problems in Industry

A. Petroleum Production and Refining

76. Allen, F. H. and McCabe E., "The Microflora of Several West Texas Oil Field Brines and Their Relation to Corrosion", Proc. Trans. Texas Acad. Sci., 27:219-222, 1944.

77. A. P. I. Refining Report, "Probes Prove Talented Corrosion Sleuths", Oil Gas J., 58(20):135-138, May, 1960.

78. Bastin, E. S. and Greer, F. E., "Additional Data on Sulphate-Reducing Bacteria in Soils and Waters of Illinois Oil Fields", Bull. Am. Assoc. Petrol. Geologists, 14:153-159, 1930.

79. Caldwell, J. A. and Lytle, M. L., "Bacterial Corrosion of Offshore Structures", Corrosion, 9:192-196, June, 1953.

80. Colberg, G. W., "Tank Coatings: Clean-Oil Tankers", Marine Eng., 61(8):53-54, 57, Aug., 1956.

81. Crawford, Paul B., "What's Ahead in Oil Recovery?", Petrol. Eng., Jan., 1961.

82. Davis, J. B. and Updegraff, D. M., "Microbiology in the Petroleum Industry", Bacteriol. Rev., 18:215-238, 1954.

83. Doig, Keith and Wachter, Aaron, "Bacterial Casing Corrosion in the Ventura Field", Corrosion, 7:212-224, July, 1951.

84. Dravnieks, A. and Freedman, A. J., "Electrical Probes Monitor Corrosion", Petrol. Refiner, July, 1958.

85. Freedman, A. J., Troscinski, E. S. and Dravnieks, A., "An Electrical Resistance Method of Corrosion Monitoring in Refinery Equipment", Corrosion, 14:175t-178t, April, 1958.

86. Gattenmeyer, J. L., Hewes, F. W. and Seager, W. H., "Corrosion Control in Oil and Gas Producing Equipment", Can. Mining Met. Bull., 49:31-36, Jan., 1956.

87. Hadley, R. F., "The Microbiological Corrosion of Natural Gas Pipe Lines", Gas, 16:36, 1940.

88. Harris, J. O., "Bacterial Activity at the Bottom of Back-Filled Pipeline Ditches", Presented at Conf. National Assoc. Corrosion Engineers, Oct., 1959.

89. Kuznetsov, S.I., "Principal Results in the Investigation of the Microflora of Oil Deposits", (In Russian), Mikrobiologiya, 26(6): 651-658, 1957.

90. Mukaraev, A. A. and Travnitsky, V. N., "Corrosion of Equipment in the Ishimbay Oil Works and Measures to Combat It", (In Russian), Bash. Neft, 2:35, 1951.

91. Osnitskaia, L. K., "Microbiological Study of Water Strata of Oil Deposits of East Carpathian Regions", (In Russian), Mikrobiologiya, 27(4): 478-483, 1958.

92. Sharpley, J. M., "Bacteria in Flood Water-What They Are-What They Mean", Petrol. Eng., Feb., 1961.

93. Shelomentsev, I. I., "Corrosion and Combative Measures in the Oil Industry of Second Baku", (In Russian), Moscow Gostoptekhizdat, 1948.

94. St. Bonaventure University "Sulphate-Reducing Bacteria - Their Relation to the Secondary Recovery of Oil", Science Symposium, 1957.

95. Tant, C. O., "The Isolation of Clostridium Species from Secondary Recovery and Salt Water Disposal Systems", Presented at Proc. Soc. Amer. Bact., Texas Branch, April 1-2, 1960.

96. Vorob'yeva, G. L., "A Study of the Role of Bacteria of the Pseudomonas Type in Petroleum Microbiology", (In Russian), Doklady Akad. Nauk S.S.S.R., 112(4):763-765, 1957.

97. Wolfson, L. L., "Microbiology in Secondary Recovery Systems", Corrosion, 15(6):298-300, June, 1960.

B. Metal-Cutting Fluids

98. Bennett, E. O., "The Role of Sulphate-Reducing Bacteria in the Deterioration of Cutting Emulsions", Lubrication Eng., 13:215-219, April, 1957.

99. Bennett, E. O. and Wheeler, H. C., "Survival of Bacteria in Cutting Oil", Appl. Microbiol., 2:368-371, Nov., 1954.

100. Duffett, N. D., Gold, S. H. and Weirich, C. L., "Growth of Bacteria in Cutting Oils", J. Bacteriol., 45:37, 1943.

101. Ellis, Lee F., et al, "Oxidation of Components of Soluble Oils", Appl. Microbiol., 5:345-348, Nov., 1957.

102. Fabian, F. W. and Pivnick, Hilliard, "Growth of Bacteria in Soluble Oil Emulsions", Appl. Microbiol., 2:199-203, July, 1953.

103. Guynes, G. J. and Bennett, E. O., "Bacterial Deterioration of Emulsion Oils. I. Relationship Between Aerobes and Sulfate-Reducing Bacteria in Deterioration", Appl. Microbiol., 7:117-121, March, 1959.

104. Isenberg, D. L. and Bennett, E. O., "Bacterial Deterioration of Emulsion Oils. 2. Nature of the Relationship Between Aerobes and Sulfate-Reducing Bacteria", Appl. Microbiol., 7:121-125, March, 1959.

105. Lee, M. and Chandler, A. C., "A Study of the Nature, Growth, and Control of Bacteria in Cutting Compounds", J. Bacteriol., 41:373-386, 1941.

106. Liberthson, L., "Bacterial Deterioration of Cutting Oil Emulsions", Lubrication Eng., 1:103-106, 1945.

107. Pivnick, Hilliard, "The Nutrition and Factors Affecting the Growth of Bacteria in Soluble Oils", Thesis, Michigan State College, 1952.

108. Pivnick, Hilliard, "Pseudomonas rubescens, A New Species from Soluble Oil Emulsions", J. Bacteriol., 70:1-6, July, 1955.

109. Pivnick, Hilliard, Engelhard, W. E. and Thompson, T. L., "The Growth of Pathogenic Bacteria in Soluble Oil Emulsions", Appl. Microbiol., 2:140-142, May, 1954.

110. Pivnick, Hilliard, et al, "Biological Oxidation of Soluble Oil Emulsions", Lubrication Eng., 11:96, March-April, 1955.

111. Pivnick, Hilliard, et al, "Current Research in the Bacteriology of Soluble Oil Emulsions", Lubrication Eng., 12:310-315, Sept-Oct., 1956.

112. Sabina, L. R. and Pivnick, Hilliard, "Oxidation of Soluble Oil Emulsions and Emulsifiers by Pseudomonas oleovorans and Pseudomonas formicans", Appl. Microbiol., 4:171-175, July 1956.

113. Samuel-Maharajah, R., et al, "The Coexistence of Pathogens and Pseudomonads in Soluble Oil Emulsions", Appl. Microbiol., 4:293-299, Nov., 1956.

114. Sonntag, W., "Bacterial Decomposition of Soluble-Oil Emulsions", Lubrication Eng., 8:234,260, Oct., 1952.

115. Tant, C. O. and Bennett, E. O., "The Growth of Aerobic Bacteria in Metal-Cutting Fluids", Appl. Microbiol., 6:388-391, Nov., 1958.

C. Miscellaneous

116. Deuber, Carl G., "The Present Status of Bacterial Corrosion Investigations in the United States", Corrosion, 9:95-99, March, 1953.

117. Dravnieks, A. and Cataldi, H. A., "Industrial Applications of a Method for Measuring Small Amounts of Corrosion Without Removal of Corrosion Products", Corrosion, 10:224-230, July, 1954.

118. Erben, A. R., "Cathodic Polarization of Steel in Salt Water", Corrosion, 17:222t-226t, May, 1961.

119. Nette, I. T., Pomortseva, N. V. and Kozlova, E. I., "Destruction of Rubber by Microorganisms", (In Russian), Mikrobiologiya, 28(6):881-886, 1959.

120. Rogers, T. Howard, "The Promotion and Acceleration of Metallic Corrosion by Microorganisms", J. Inst. Metals, 75:19-38, Sept., 1943.

121. Snoke, Lloyd R., "Marine Tests of Organic Materials", Bell Labs. Record, 35:287-292, Aug., 1957.

122. Snoke, Lloyd R., "Resistance of Organic Materials and Cable Structures to Marine Biological Attack", Bell System Tech. J., 36:1095-1127, Sept., 1957.

123. Zobell, C. E. and Beckwith, Josephine D., "The Deterioration of Rubber Products by Micro-Organisms", J. Am. Water Works Assoc., 36:439-452, April, 1944.

IV The Relationship Between Sulphate-Reducing Bacteria and Corrosion

124. Adams, Mary E. and Farrer, T. W., "The Influence of Ferrous Iron on Bacterial Corrosion", J. Appl. Chem. (London), 3:117-120, March, 1953.

125. Adams, Mary E. and Postgate, J. R., "A New Sulphate-Reducing Vibrio", J. Gen. Microbiol., 20:252-257, April, 1959.

126. Bunker, H. J., "Microbiological Experiments in Anaerobic Corrosion", J. Soc. Chem. Ind. (London), 58:93-100, 1939.

127. Bunker, H. J., "The Microbiological Aspect of Anaerobic Corrosion", Second Cong. Mondial du Pétrole, Paris (R348-5.3), pp. 1-3, 1937.

128. Butlin, K. R., "Some Malodorous Activities of Sulphate-Reducing Bacteria", Proc. Soc. Appl. Bacteriol., 12(2):39-42, 1949.

129. Butlin, K. R., Adams, Mary and Thomas, Margaret, "Sulphate-Reducing Bacteria and Internal Corrosion of Ferrous Pipes Conveying Water", Nature, 163:26-27, Jan., 1949.

130. Butlin, K. R., Adams, M. E. and Thomas, M., "The Morphology of Sulphate-Reducing Bacteria", J. Gen. Microbiol., 3:3-4, 1949.

131. Butlin, K. R., "The Bacterial Sulphur Cycle", Research (London), 6:184-191, May, 1953.

132. Ginter, R. L., "Causative Agents of Sulphate Reduction in Oil-Well Waters", Bull. Am. Assoc. Petrol. Geologists, 14:139-152, 1930.

133. Grossman, J. P. and Postgate, J. R., "The Metabolism of Malate and Certain Other Compounds by Desulphovibrio desulphuricans", J. Gen. Microbiol., 12:429-445, June, 1955.

134. Hadley, R. P., "Studies in Microbiological Anaerobic Corrosion", Bull. Am. Gas Assoc., p. 23, 1940.

135. Hunter, J. B., McConomy, H. F. and Weston, R. F., "Environmental pH as a Factor in Control of Anaerobic Bacterial Corrosion", Corrosion, 4:567-581, Dec., 1948.

136. Littlewood, Dorothy and Postgate, J. R., "On the Osmotic Behavior of Desulphovibrio desulphuricans", J. Gen. Microbiol., 16:596-603, June, 1957.

137. Littlewood, Dorothy and Postgate, J. R., "Sodium Chloride and the Growth of Desulphovibrio desulphuricans", J. Gen. Microbiol., 17:378-389, Oct., 1957.

138. Miller, Lawrence, "Rapid Formation of High Concentrations of Hydrogen Sulphide by Sulfate-Reducing Bacteria", Contrib. Boyce Thompson Inst., 15:437-465, Oct.-Dec., 1949.

139. Minchin, L. T., "Corrosion of Pipes by Bacteria. A European Survey of Microbiological Anaerobic Corrosion with Special Reference to Experience in Low Countries", Gas Age, 114(8):45-47, 101-102, Oct., 1954.

140. Postgate, J. R., "On the Nutrition of Desulphovibrio desulphuricans", J. Gen. Microbiol., 5:714-724, Oct., 1951.

141. Postgate, J. R., "The Reduction of Sulphur Compounds by Desulphovibrio desulphuricans". J. Gen. Microbiol., 5:725-738, Oct., 1951.

142. Postgate, J. R., "Cytochrome c_3 and Desulphoviridin; Pigments of the Anaerobe Desulphovibrio desulphuricans", J. Gen. Microbiol., 14:545-572, June, 1956.

143. Postgate, J. R., "Iron and the Synthesis of Cytochrome c_3", J. Gen. Microbiol., 15:186-193, Aug., 1956.

144. Postgate, J. R., "Microbial Transformations of Inorganic Sulphur Compounds", The Chem. Soc., (London), Special Publication No. 12:391-400, 1958.

145. Postgate, J. R., "The Chemical Physiology of the Sulphate-Reducing Bacteria", Producers Monthly, 22(9):12-16, July, 1958.

146. Postgate, J. R., "A Diagnostic Reaction of Desulphovibrio desulphuricans", Nature, 183:481-482, Feb., 1959.

147. Postgate, J. R., "On the Autotrophy of Desulphovibrio desulphuricans", Z. allgem. Mikrobiol., 1:53-56, 1960.

148. Postgate, J. R., "The Economic Activities of Sulphate-Reducing Bacteria", Progress in Industrial Microbiology, 2:49-69, 1960.

149. Spruit, C. J. P. and Wanklyn, J. M., "Iron/Sulphide Ratios in Corrosion by Sulphate-Reducing Bacteria", Nature, 168:951-952, Dec., 1951.

150. Starkey, Robert L., "Sulfate Reduction and the Anaerobic Corrosion of Iron", Antonie van Leeuwenhoek, J. Microbiol. Serol., 12:193-203, 1947.

151. Starkey, Robert L., "The Relationship of Sulfate-Reducing Bacteria to Iron Corrosion in the Marine Environment", Proc. 6th Intern. Congress Microbiol., 3:326-327, Sept., 1953.

152. Starkey, Robert L , "Transformations of Sulfur by Microorganisms", Ind. Eng. Chem., 48:1429-1437, Sept., 1956.

153. Starkey, Robert L., "The General Physiology of the Sulfate-Reducing Bacteria in Relation to Corrosion", Producers Monthly, 22(9):12-30, June, 1958.

154. Starkey, Robert L., "Sulfate-Reducing Bacteria - Physiology and Practical Significance", Lecture Presented at University of Maryland, Oct. 20, 1960.

155. Starkey, Robert L. and Wight, Kent M., "Anaerobic Corrosion of Iron in Soil, with Particular Consideration of the Soil Redox Potential as an Indicator of Corrosiveness:, Proc. Am. Gas Assoc., 25:307-412, 1945.

156. Summer, W., "Microbially Induced Corrosion", Corrosion Technology, pp. 287-288, Sept., 1960.

157. Updegraff, D. M., "Microbiological Corrosion of Iron and Steel", Corrosion, 11:442t-446t, 1955.

158. Wilson, O. B., "Anaerobic Corrosion of Buried Iron Pipes", Water & Water Eng., 48:594-598, Nov., 1945.

159. Wormwell, F. and Farrer, T. W., "Electrochemical Studies of Anaerobic Corrosion in Presence of Sulphate-Reducing Bacteria", Chem.& Ind. (London), pp. 108-109, 1952.

160. Zobell, C. E., "Ecology of Sulfate-Reducing Bacteria", Producers Monthly, 22(7):12, 14, 16, 18, 20-23, 26-29, May, 1958.

161. Zobell, C. E. and Rittenberg, S. C., "Sulfate-Reducing Bacteria in Marine Sediments", J. Marine Research, 7:602-617, 1948.

V Progress in the Inhibition of Microbially Induced Deterioration and Corrosion

162. Allen, F. H., "The Microbiological Aspects of Gasoline Inhibition", J. Inst. Petrol., 31:9-15, 1945.

163. Allred, R. C., "The Role of Microorganisms in Oil Field Water Flooding Operations; Bacterial Control on North Burbank Unit Water Flood, Osage County, Oklahoma", Producers Monthly, 18(4):18-22, Feb., 1954.

164. Allred, R. C., Mills, T. A. and Fisher, H. B., "Bacteriological Techniques Applicable to the Control of Sulfate-Reducing Bacteria in Water Flooding Operations", Producers Monthly, 19(2):31-32, 1954.

165. Allred, R. C., et al, "Corrosion is Controlled by Bactericide Treatment", World Oil, Nov., 1959.

166. Anderson, K. E. and Yackovich, F., "The Effects of Bactericides on the Microorganisms in Oil-Flooding Waters", Science Studies, 17:33-63, Oct., 1955.

167. Anderson, K. E., et al, "The Development of New Bactericides and Flood Water Treatment Based Upon the Physiology of the Sulfate-Reducing Bacteria", Producers Monthly, 22(10):10-25, Aug., 1958.

168. Bennett, E. O. "Control of Bacterial Spoilage of Emulsion Oils", Soap Chem. Specialties, 32(10):47-59, Oct., 1956.

169. Bennett, E. O., "Control of Bacterial Spoilage of Emulsion Oils. Part 2.", Soap Chem. Specialties, 32(11):46-48, 155, Nov., 1956.

170. Bennett, E. O., Adamson, C. L. and Feisal, V. E., "Factors Involved in the Control of Microbial Deterioration", Appl. Microbiol., 7(6):368-372, Nov., 1959.

171. Bennett, E. O. and Bauerle, R. H., "The Sensitivities of Mixed Populations of Bacteria to Inhibitors", Australian J. Biol. Sci., 13(2):142-149, 1960.

172. Brandeberry, L. J. and Myers, H. W., Jr., "Test Procedures for Compounds Used as Preservatives in Industrial Coolants", Lubrication Eng., pp. 161-164, April, 1960.

173. Caldwell, Joseph A. and Lytle, Melba L., U. S. Patent 2,906,708, Sept.29, 1959.

174. Cannon, W. N., "Bacterial Inhibition in Metal Working Fluids", Lilly Research Laboratories, Eli Lilly and Company, Indianapolis, Indiana, 1958.

175. Drummond, J. P. M. and Postgate, J. R., "A Note on the Enumeration of Sulphate-Reducing Bacteria in Polluted Water and on Their Inhibition by Chromate", J. Appl. Bact., 18:307-311, 1955.

176. Guynes, G. J. and Bennett, E. O., "The Sensitivity of Sulphate-Reducing Bacteria to Antibacterial Agents (The Mercurials)", Producers Monthly, 23:15-17, 1958.

177. Harris, Rhett G. and Strawinski, Raymond J., U. S. Patent 2,680,058, June 1, 1954.

178. Klemme, Dorothea E. and Leonard, John M., "Microbial Inhibitors for Systems of Jet Fuel and Water", Naval Research Laboratory, NRL Report 5501, Aug. 31, 1960.

179. Kusnetsova, V. A., et al, "A Contribution to the Inhibition of Development of the Sulphate Reducing Bacteria in the Oil Field of the Kalinovka Layer" (In Russian), Mikrobiologiya, 26:330-337, May/June, 1957.

180. Lawrence, C. A., "Surface-Active Quaternary Ammonium Germicides", Academic Press, Inc., New York, N. Y., 1950.

181. Little, Paul A. and Gambill, Marvin, "Rapid Evaluation of Corrosion Inhibitors", Petrol. Eng., Feb., 1960.

182. Morgan, John D. and Lowe, Russell E., U. S. Patent 2,566,068, Aug. 28, 1951.

183. Oppenheimer, C. H., "How to Detect and Control Corrosion-Causing Bacteria", World Oil, 147(7):144-147, Dec., 1958.

184. Pivnick, Hilliard and Fabian, F. W., "Methods for Testing the Germicidal Value of Chemical Compounds for Disinfecting Soluble Oil Emulsions", Appl. Microbiol., 1:204-207, July, 1953.

185. Pivnick, Hilliard and Fotopoulos, C. K., "Disinfection of Soluble Oil Emulsions", Lubrication Eng., 13:151-156, March, 1957.

186. Prince, H. N., "Specific Inhibition of Obligate Anaerobes", Nature, 186:816-818, 1960.

187. Rogers, T. H., "The Inhibition of Sulphate-Reducing Bacteria by Dyestuffs. Part II. Practical Application in Cable Storage Tanks and Gas Holders", J. Soc. Chem. Ind. (London), 64:292-295, 1945.

188. Rosenfeld, M., "Theoretical Considerations of Corrosion and Hydrogen Embrittlement Inhibition", Report No. CCL 88, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland, Jan. 12, 1960.

189. Therrell, F. A., Jr., "Economics of Cathodic Protection", Presented at Annual Conf. Nat. Assoc. Corrosion Eng., Southcentral Region, Tulsa, Oklahoma, Oct. 25-27, 1960.

190. Watkins, Franklin M., "Corrosion Protection of Fuel-Handling Equipment", Quartermaster Rev., 40(3):31, 138, 143-147, Nov.-Dec., 1960.

191. Westveer, W. M. and Brosier, J. S., "Preventing Bacterial Growth in Oil Emulsions", Metal Progr., 56:357-358, Sept., 1949.

192. Wheeler, H. O. and Bennett, E. O., "Bacterial Inhibitors for Cutting Oil", Appl. Microbiol., 4:122-126, May, 1956.

193. Yackovich, F., "The Effect of Bactericides Upon Microorganisms Isolated from Oil Flood Waters", Thesis, St. Bonaventure University, 1955.

194. Yackovich, F., "Detect Sulfate Reducers and Evaluate Bactericides in Flood Water", Petrol. Eng., April, 1961.

VI Laboratory Procedures Used In Petroleum Microbiology

195. Abd-El-Malek, Y. and Rizk, S. G., "Counting of Sulphate-Reducing Bacteria in Mixed Bacterial Populations", Nature, 182:538, Aug., 1958.

196. Bradford, B. W., Harvey, D. and Chalkley, D. F., "The Chromatographic Analysis of Hydrocarbon Mixtures", J. Inst. Petrol., 41:80-91, 1955.

197. Butlin, K. R., Adams, M. E. and Thomas, M., "The Isolation and Cultivation of Sulphate-Reducing Bacteria", J. Gen. Microbiol., 3:46-59, 1949.

198. Desty, D. H. and Whyman, B. H. F., "Application of Gas-Liquid Chromatography to Analysis of Liquid Petroleum Fractions", Anal. Chem., 29(3):320-329, March, 1957.

199. Dostálek, Milan and Spurný, Milos, "Characteristics on Culturing of Sulphate-Reducing Bacteria from Oil Deposits" (In Czech), Ceskoslov. mikrobiol., 1:158-164, 1956.

200. Dworkin, Martin, "Studies on Pseudomonas methanica (Söhngen) Nov. Comb.", J. Bacteriol., 72:646-659, Nov., 1956.

201. Eggertsen, F. T. and Groennings, S., "Determination of Five-to Seven-Carbon Saturates by Gas Chromatography", Anal. Chem., 30(1):20-25, Jan., 1958.

202. Eggertsen, F. T. and Knight, H. S., "Gas Chromatography - Effect of Type and Amount of Solvent on Analysis of Saturated Hydrocarbons", Anal. Chem., 30(1):15-20, Jan., 1958.

203. Egorova, A. A. and Deriugina, Z. P., "A New Method of Producing Microscopic Preparations from Petroleum" (In Russian), Mikrobiologiya, 27:501-502, July/Aug., 1958.

204. Favre, J. A., Hines, W. J. and Smith, D. E., "How Phillips Applied Chromatography", Petrol. Refiner, 37(11):251-254, 1958.

205. Fredericks, E. M. and Brooks, F. R., "Gas Chromatography - Analysis of Gaseous Hydrocarbons by Gas-Liquid Partition Chromatography", Anal. Chem., 28(3):297-303, March, 1956.

206. Garrett, W. D. and Krynitsky, J. A., "Determination of Water in Hydrocarbon Fuels", Naval Research Laboratory, NRL Report No. 4997, Sept. 4, 1957.

207. Grossman, J. P. and Postgate, J. R., "Cultivation of Sulphate-Reducing Bacteria", Nature, 171:600-602, April, 1953.

208. Grossman, J. P. and Postgate, J. R., "The Estimation of Sulphate-Reducing Bacteria", Proc. Soc. Appl. Bacteriol., 16:1-9, April, 1953.

209. Hartsell, S. E., "The Preservation of Bacterial Cultures Under Paraffin Oil", Appl. Microbiol., 1(1):36-41, Jan., 1953.

210. Hartsell, S. E., "Microbiological Process Report. Maintenance of Cultures Under Paraffin Oil", Appl. Microbiol., 4:350-355, Nov., 1956.

211. Keulemans, A. I. M. and Kwantes, A., "Analysis of Volatile Organic Compounds by Means of Vapor-Phase Chromatography", Presented at World Petrol. Congress, Rome, Italy, June, 1955.

212. Knight, H. S., "Gas Chromatography of Olefins - Determination of Pentenes and Hexenes in Gasoline", Anal. Chem., 30(1):9-15, Jan., 1958.

213. Knight, H. S., et al, "Chromatographic Determination of Gum in Fuels", Anal. Chem., 28(1):8-11, Jan., 1956.

214. Knox, John F., "Gas Chromatography", Science Progress, 45:227-243, 1957.

215. Lichtenfels, D. H., et al, "Gas Partition Analysis of Light Ends in Gasoline", Presented at Pittsburgh Conf. on Anal. Chem. and Appl. Spectroscopy, Feb. 29, 1956.

216. McEwen, D. J., "The Separation of the Light Hydrocarbons by Gas Chromatography", Chem. in Can., 11(10):35-37, 1959.

217. Pivnick, Hilliard and Sabine, L. R., "Studies of *Aeromonas formicans* Crawford comb. Nov. from Soluble Oil Emulsions", J. Bacteriol., 73:247-252, Feb., 1957.

218. Postgate, J. R., "Growth of Sulphate-Reducing Bacteria in Sulphate-Free Media", Research, 5:189-191, 1952.

219. Postgate, J. R., "Differential Media for Sulphur Bacteria", J. Sci. Food Agr., 10(12):669-674, Dec., 1959.

220. Rosen, A. A. and Middleton, F. M., "Identification of Petroleum Refinery Wastes in Surface Waters", Anal. Chem., 27(5):790-794, May, 1955.

221. Rossini, Frederick D., "Hydrocarbons in Petroleum", J. Chem. Educ., 37:554-561, Nov., 1960.

222. Rowan, Robert, Jr., "Identification of Hydrocarbon Peaks in Gas Chromatography by Sequential Application of Class Reactions", Anal. Chem., 33(6):658-665, May, 1961.