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THE HEAT OF ADSORPTION
OF

HYDRATED SILICA GEL

THESIS FOR THE DEGREE OF M. S.

M. M. Nasif

1931

100% SILICA GEL
100% SILICA GEL

Silica gel

THE HEAT OF ADSORPTION
of
HYDRATED SILICA GEL

A Thesis
Submitted to the Faculty
of
MICHIGAN STATE COLLEGE

In Partial Fulfillment of the
Requirements for the Degree

of

Master of Science
Department of Chemistry

By
M. M. Nasif
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1931

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THE HEAT OF ADSORPTION OF HYDRATED SILICA GEL

HISTORICAL

A considerable amount of research has been done in recent years on the properties of silica gel, especially on its property of adsorption. This property and related phenomena has been investigated extensively during recent years in this laboratory. As a continuation of this work, the heat of adsorption of hydrated silica gel has been carried out with the purpose of determining the heat of adsorption of the gel when it has varying amounts of water on it. Also the heat of adsorption of the gel was determined in acid and alkaline solutions and determinations were made to determine if the gel adsorbed any acid or alkali.

Patrick and Grimm¹ did some work on the heat of wetting of silica gel. They obtained values for this property of the gel, using the following liquids: water, ethyl alcohol, aniline, benzene and carbon tetrachloride. They did not evacuate their gel and they also used gel which had been finely divided. Since the gel they used was not evacuated it would not be expected that their results were the maximum. They conceived of silica gel as to have been a mass of silica nuclei, each nuclei being surrounded

1. *Chlorophyll a* (Chl *a*)

the 1990s, the number of people in the world who are under 15 years of age is expected to increase from 1.1 billion to 1.5 billion. The number of people aged 65 and over is expected to increase from 200 million to 400 million. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion. The number of people aged 15 and over is expected to increase from 3.5 billion to 4.5 billion.

with a thin film of water. Having such a conception of silica gel they accounted for the heat of adsorption or wetting on the basis of surface energy changes that took place at the surface of each nuclei.

Much research has been done on the heat of adsorption of soils. Bouyoucos² says that in the case of soils the maximum is reached when the soil has been heated to 107°C. for 24 hours. He also states that the amount of water necessary to produce the heat is comparatively small. In an other article he says that the temperature rise of water by sudden compression amounts to 0.018°C. per 10 atmospheres, and that the force of compression rises to such large values as 156 atmospheres.

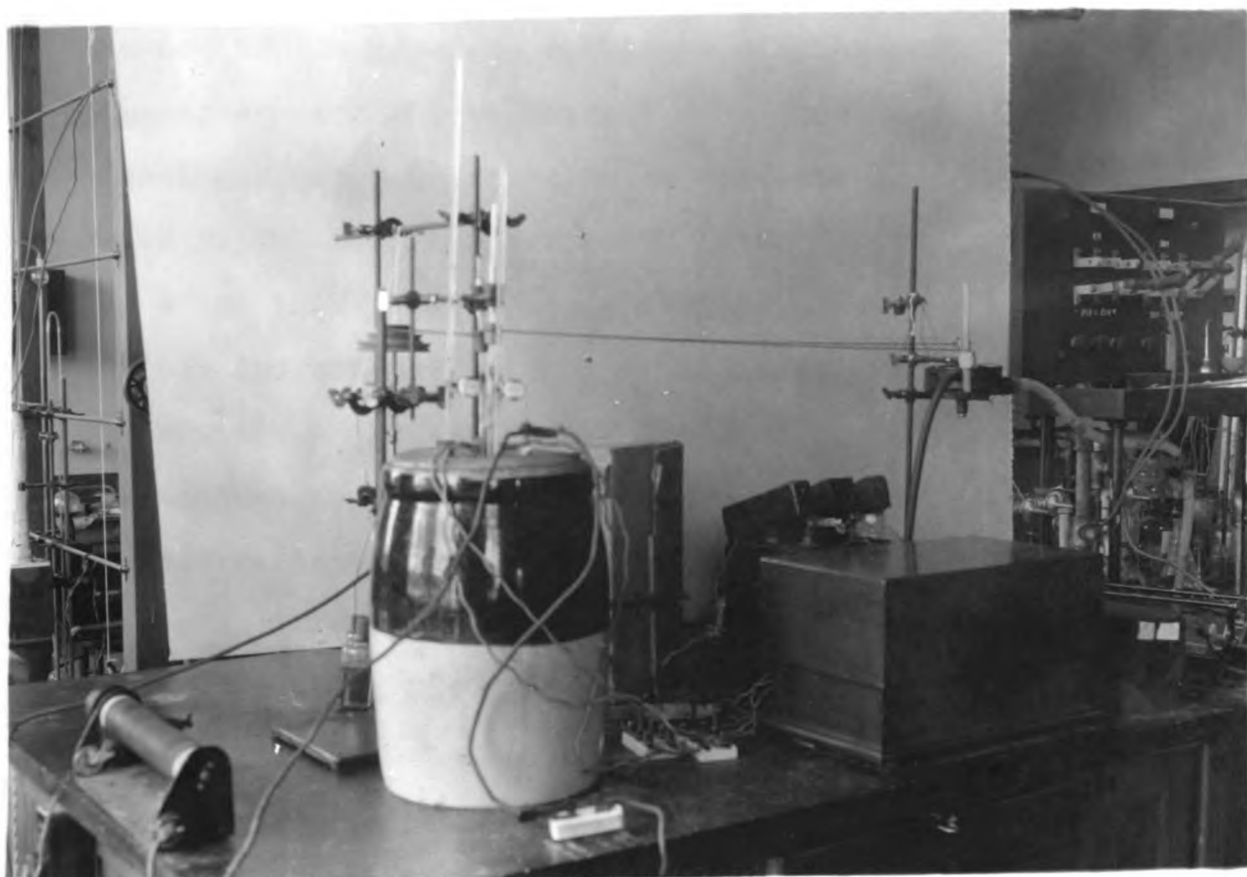
The heats of adsorption of some eleven organic liquids on charcoal were determined by Lamb and Coolidge³. They determined the heats of adsorption by the expression $h = mx^n$, where h represents the heat of adsorption per c.c. of vapor, x the number of c.c. of vapor adsorbed, and m and n characteristic constants of the vapor adsorbed.

the following: (1) the fact that the 1911-12 season was
the first in which the total catch was less than 100
tons; (2) the fact that the 1912-13 season was the first
in which the total catch was less than 50 tons; (3) the fact
that the 1913-14 season was the first in which the total
catch was less than 25 tons; (4) the fact that the 1914-15
season was the first in which the total catch was less than
10 tons; (5) the fact that the 1915-16 season was the first
in which the total catch was less than 5 tons; (6) the fact
that the 1916-17 season was the first in which the total
catch was less than 2 tons; (7) the fact that the 1917-18
season was the first in which the total catch was less than
1 ton; (8) the fact that the 1918-19 season was the first
in which the total catch was less than 1/2 ton; (9) the fact
that the 1919-20 season was the first in which the total
catch was less than 1/4 ton; (10) the fact that the 1920-21
season was the first in which the total catch was less than
1/8 ton; (11) the fact that the 1921-22 season was the first
in which the total catch was less than 1/16 ton; (12) the fact
that the 1922-23 season was the first in which the total
catch was less than 1/32 ton; (13) the fact that the 1923-24
season was the first in which the total catch was less than
1/64 ton; (14) the fact that the 1924-25 season was the first
in which the total catch was less than 1/128 ton; (15) the fact
that the 1925-26 season was the first in which the total
catch was less than 1/256 ton; (16) the fact that the 1926-27
season was the first in which the total catch was less than
1/512 ton; (17) the fact that the 1927-28 season was the first
in which the total catch was less than 1/1024 ton; (18) the fact
that the 1928-29 season was the first in which the total
catch was less than 1/2048 ton; (19) the fact that the 1929-30
season was the first in which the total catch was less than
1/4096 ton; (20) the fact that the 1930-31 season was the first
in which the total catch was less than 1/8192 ton; (21) the fact
that the 1931-32 season was the first in which the total
catch was less than 1/16384 ton; (22) the fact that the 1932-33
season was the first in which the total catch was less than
1/32768 ton; (23) the fact that the 1933-34 season was the first
in which the total catch was less than 1/65536 ton; (24) the fact
that the 1934-35 season was the first in which the total
catch was less than 1/131072 ton; (25) the fact that the 1935-36
season was the first in which the total catch was less than
1/262144 ton; (26) the fact that the 1936-37 season was the first
in which the total catch was less than 1/524288 ton; (27) the fact
that the 1937-38 season was the first in which the total
catch was less than 1/1048576 ton; (28) the fact that the 1938-39
season was the first in which the total catch was less than
1/2097152 ton; (29) the fact that the 1939-40 season was the first
in which the total catch was less than 1/4194304 ton; (30) the fact
that the 1940-41 season was the first in which the total
catch was less than 1/8388608 ton; (31) the fact that the 1941-42
season was the first in which the total catch was less than
1/16777216 ton; (32) the fact that the 1942-43 season was the first
in which the total catch was less than 1/33554432 ton; (33) the fact
that the 1943-44 season was the first in which the total
catch was less than 1/67108864 ton; (34) the fact that the 1944-45
season was the first in which the total catch was less than
1/134217728 ton; (35) the fact that the 1945-46 season was the first
in which the total catch was less than 1/268435456 ton; (36) the fact
that the 1946-47 season was the first in which the total
catch was less than 1/536870912 ton; (37) the fact that the 1947-48
season was the first in which the total catch was less than
1/1073741824 ton; (38) the fact that the 1948-49 season was the first
in which the total catch was less than 1/2147483648 ton; (39) the fact
that the 1949-50 season was the first in which the total
catch was less than 1/4294967296 ton; (40) the fact that the 1950-51
season was the first in which the total catch was less than
1/8589934592 ton; (41) the fact that the 1951-52 season was the first
in which the total catch was less than 1/17179869184 ton; (42) the fact
that the 1952-53 season was the first in which the total
catch was less than 1/34359738368 ton; (43) the fact that the 1953-54
season was the first in which the total catch was less than
1/68719476736 ton; (44) the fact that the 1954-55 season was the first
in which the total catch was less than 1/137438953472 ton; (45) the fact
that the 1955-56 season was the first in which the total
catch was less than 1/274877906944 ton; (46) the fact that the 1956-57
season was the first in which the total catch was less than
1/549755813888 ton; (47) the fact that the 1957-58 season was the first
in which the total catch was less than 1/1099511627776 ton; (48) the fact
that the 1958-59 season was the first in which the total
catch was less than 1/2199023255552 ton; (49) the fact that the 1959-60
season was the first in which the total catch was less than
1/4398046511104 ton; (50) the fact that the 1960-61 season was the first
in which the total catch was less than 1/8796093022208 ton; (51) the fact
that the 1961-62 season was the first in which the total
catch was less than 1/17592186044416 ton; (52) the fact that the 1962-63
season was the first in which the total catch was less than
1/35184372088832 ton; (53) the fact that the 1963-64 season was the first
in which the total catch was less than 1/70368744177664 ton; (54) the fact
that the 1964-65 season was the first in which the total
catch was less than 1/140737488355328 ton; (55) the fact that the 1965-66
season was the first in which the total catch was less than
1/281474976710656 ton; (56) the fact that the 1966-67 season was the first
in which the total catch was less than 1/562949953421312 ton; (57) the fact
that the 1967-68 season was the first in which the total
catch was less than 1/1125899906842624 ton; (58) the fact that the 1968-69
season was the first in which the total catch was less than
1/2251799813685248 ton; (59) the fact that the 1969-70 season was the first
in which the total catch was less than 1/4503599627370496 ton; (60) the fact
that the 1970-71 season was the first in which the total
catch was less than 1/9007199254740992 ton; (61) the fact that the 1971-72
season was the first in which the total catch was less than
1/18014398509481984 ton; (62) the fact that the 1972-73 season was the first
in which the total catch was less than 1/36028797018963968 ton; (63) the fact
that the 1973-74 season was the first in which the total
catch was less than 1/72057594037927936 ton; (64) the fact that the 1974-75
season was the first in which the total catch was less than
1/144115188075855872 ton; (65) the fact that the 1975-76 season was the first
in which the total catch was less than 1/288230376151711744 ton; (66) the fact
that the 1976-77 season was the first in which the total
catch was less than 1/576460752303423488 ton; (67) the fact that the 1977-78
season was the first in which the total catch was less than
1/1152921504606846976 ton; (68) the fact that the 1978-79 season was the first
in which the total catch was less than 1/2305843009213693952 ton; (69) the fact
that the 1979-80 season was the first in which the total
catch was less than 1/4611686018427387904 ton; (70) the fact that the 1980-81
season was the first in which the total catch was less than
1/9223372036854775808 ton; (71) the fact that the 1981-82 season was the first
in which the total catch was less than 1/18446744073709551616 ton; (72) the fact
that the 1982-83 season was the first in which the total
catch was less than 1/36893488147419103232 ton; (73) the fact that the 1983-84
season was the first in which the total catch was less than
1/73786976294838206464 ton; (74) the fact that the 1984-85 season was the first
in which the total catch was less than 1/147573952589676412928 ton; (75) the fact
that the 1985-86 season was the first in which the total
catch was less than 1/295147905179352825856 ton; (76) the fact that the 1986-87
season was the first in which the total catch was less than
1/590295810358705651712 ton; (77) the fact that the 1987-88 season was the first
in which the total catch was less than 1/1180591620717411303424 ton; (78) the fact
that the 1988-89 season was the first in which the total
catch was less than 1/2361183241434822606848 ton; (79) the fact that the 1989-90
season was the first in which the total catch was less than
1/4722366482869645213696 ton; (80) the fact that the 1990-91 season was the first
in which the total catch was less than 1/9444732965739290427392 ton; (81) the fact
that the 1991-92 season was the first in which the total
catch was less than 1/18889465931478580854784 ton; (82) the fact that the 1992-93
season was the first in which the total catch was less than
1/37778931862957161709568 ton; (83) the fact that the 1993-94 season was the first
in which the total catch was less than 1/75557863725914323419136 ton; (84) the fact
that the 1994-95 season was the first in which the total
catch was less than 1/151115727451828646838272 ton; (85) the fact that the 1995-96
season was the first in which the total catch was less than
1/302231454903657293676544 ton; (86) the fact that the 1996-97 season was the first
in which the total catch was less than 1/604462909807314587353088 ton; (87) the fact
that the 1997-98 season was the first in which the total
catch was less than 1/1208925819614629174706176 ton; (88) the fact that the 1998-99
season was the first in which the total catch was less than
1/2417851639229258349412352 ton; (89) the fact that the 1999-00 season was the first
in which the total catch was less than 1/4835703278458516698824704 ton; (90) the fact
that the 2000-01 season was the first in which the total
catch was less than 1/9671406556917033397649408 ton; (91) the fact that the 2001-02
season was the first in which the total catch was less than
1/19342813113834066795298816 ton; (92) the fact that the 2002-03 season was the first
in which the total catch was less than 1/38685626227668133590597632 ton; (93) the fact
that the 2003-04 season was the first in which the total
catch was less than 1/77371252455336267181195264 ton; (94) the fact that the 2004-05
season was the first in which the total catch was less than
1/154742504910672534362390528 ton; (95) the fact that the 2005-06 season was the first
in which the total catch was less than 1/309485009821345068724781056 ton; (96) the fact
that the 2006-07 season was the first in which the total
catch was less than 1/618970019642690137449562112 ton; (97) the fact that the 2007-08
season was the first in which the total catch was less than
1/1237940039285380274899124224 ton; (98) the fact that the 2008-09 season was the first
in which the total catch was less than 1/2475880078570760549798248448 ton; (99) the fact
that the 2009-10 season was the first in which the total
catch was less than 1/4951760157141521099596496896 ton; (100) the fact that the 2010-11
season was the first in which the total catch was less than
1/9903520314283042199192993792 ton; (101) the fact that the 2011-12 season was the first
in which the total catch was less than 1/19807040628566084398385987584 ton; (102) the fact
that the 2012-13 season was the first in which the total
catch was less than 1/39614081257132168796771975168 ton; (103) the fact that the 2013-14
season was the first in which the total catch was less than
1/79228162514264337593543950336 ton; (104) the fact that the 2014-15 season was the first
in which the total catch was less than 1/158456325028528675187087900672 ton; (105) the fact
that the 2015-16 season was the first in which the total
catch was less than 1/316912650057057350374175801344 ton; (106) the fact that the 2016-17
season was the first in which the total catch was less than
1/633825300114114700748351602688 ton; (107) the fact that the 2017-18 season was the first
in which the total catch was less than 1/1267650600228229401496703205376 ton; (108) the fact
that the 2018-19 season was the first in which the total
catch was less than 1/2535301200456458802993406410752 ton; (109) the fact that the 2019-20
season was the first in which the total catch was less than
1/5070602400912917605986812821504 ton; (110) the fact that the 2020-21 season was the first
in which the total catch was less than 1/10141204801825835211973625643008 ton; (111) the fact
that the 2021-22 season was the first in which the total
catch was less than 1/20282409603651670423947251286016 ton; (112) the fact that the 2022-23
season was the first in which the total catch was less than
1/40564819207303340847894502572032 ton; (113) the fact that the 2023-24 season was the first
in which the total catch was less than 1/81129638414606681695789005144064 ton; (114) the fact
that the 2024-25 season was the first in which the total
catch was less than 1/162259276829213363391578010288128 ton; (115) the fact that the 2025-26
season was the first in which the total catch was less than
1/324518553658426726783156020576256 ton; (116) the fact that the 2026-27 season was the first
in which the total catch was less than 1/649037107316853453566312041152512 ton; (117) the fact
that the 2027-28 season was the first in which the total
catch was less than 1/1298074214633706907132624082305024 ton; (118) the fact that the 2028-29
season was the first in which the total catch was less than
1/2596148429267413814265248164610048 ton; (119) the fact that the 2029-30 season was the first
in which the total catch was less than 1/5192296858534827628530496329220096 ton; (120) the fact
that the 2030-31 season was the first in which the total
catch was less than 1/10384593717069655257060992658440192 ton; (121) the fact that the 2031-32
season was the first in which the total catch was less than
1/20769187434139310514121985316880384 ton; (122) the fact that the 2032-33 season was the first
in which the total catch was less than 1/41538374868278621028243970633760768 ton; (123) the fact
that the 2033-34 season was the first in which the total
catch was less than 1/83076749736557242056487941267521536 ton; (124) the fact that the 2034-35
season was the first in which the total catch was less than
1/166153499473114484112975882535043072 ton; (125) the fact that the 2035-36 season was the first
in which the total catch was less than 1/332306998946228968225951765070086144 ton; (126) the fact
that the 2036-37 season was the first in which the total
catch was less than 1/664613997892457936451903530140172288 ton; (127) the fact that the 2037-38
season was the first in which the total catch was less than
1/1329227995784915872903807060280344576 ton; (128) the fact that the 2038-39 season was the first
in which the total catch was less than 1/2658455991569831745807614120560689152 ton; (129) the fact
that the 2039-40 season was the first in which the total
catch was less than 1/5316911983139663491615228241121378304 ton; (130) the fact that the 2040-41
season was the first in which the total catch was less than
1/10633823966279326983230456482242756608 ton; (131) the fact that the 2041-42 season was the first
in which the total catch was less than 1/21267647932558653966460912964485513216 ton; (132) the fact
that the 2042-43 season was the first in which the total
catch was less than 1/42535295865117307932921825928971026432 ton; (133) the fact that the 2043-44
season was the first in which the total catch was less than
1/85070591730234615865843651857942052864 ton; (134) the fact that the 2044-45 season was the first
in which the total catch was less than 1/170141183460469231731687303715884105728 ton; (135) the fact
that the 2045-46 season was the first in which the total
catch was less than 1/340282366920938463463374607431768211456 ton; (136) the fact that the 2046-47
season was the first in which the total catch was less than
1/680564733841876926926749214863536422912 ton; (137) the fact that the 2047-48 season was the first
in which the total catch was less than 1/1361129467683753853853498429727072845824 ton; (138) the fact
that the 2048-49 season was the first in which the total
catch was less than 1/2722258935367507707706996859454145691648 ton; (139) the fact that the 2049-50
season was the first in which the total catch was less than
1/5444517870735015415413993718908291383296 ton; (140) the fact that the 2050-51 season was the first
in which the total catch was less than 1/10889035741470030830827987437816582766592 ton; (141) the fact
that the 2051-52 season was the first in which the total
catch was less than 1/21778071482940061661655974875633165533184 ton; (142) the fact that the 2052-53
season was the first in which the total catch was less than
1/43556142965880123323311949751266331066368 ton; (143) the fact that the 2053-54 season was the first
in which the total catch was less than 1/87112285931760246646623899502532662132736 ton; (144) the fact
that the 2054-55 season was the first in which the total
catch was less than 1/174224571863520493293247799005065324265472 ton; (145) the fact that the 2055-56
season was the first in which the total catch was less than
1/348449143727040986586495598010130648530944 ton; (146) the fact that the 2056-57 season was the first
in which the total catch was less than 1/696898287454081973172991196020261297061888 ton; (147) the fact
that the 2057-58 season was the first in which the total
catch was less than 1/1393796574908163946345982392040522594123776 ton; (148) the fact that the 2058-59
season was the first in which the total catch was less than
1/2787593149816327892691964784081045188247552 ton; (149) the fact that the 2059-60 season was the first
in which the total catch was less than 1/5575186299632655785383929568162090376495104 ton; (150) the fact
that the 2060-61 season was the first in which the total
catch was less than 1/11150372599265311570767859136324180752990208 ton; (151) the fact that the 2061-62
season was the first in which the total catch was less than
1/22300745198530623141535718272648361505980416 ton; (152) the fact that the 2062-63 season was the first
in which the total catch was less than 1/44601490397061246283071436545296723011960832 ton; (153) the fact
that the 2063-64 season was the first in which the total
catch was less than 1/89202980794122492566142873090593446023921664 ton; (154) the fact that the 2064-65
season was the first in which the total catch was less than
1/178405961588244985132285746181186892047843328 ton; (155) the fact that the 2065-66 season was the first
in which the total catch was less than 1/356811923176489970264571492362373784095686656 ton; (156) the fact
that the 2066-67 season was the first in which the total
catch was less than 1/713623846352979940529142984724747568191373312 ton; (157) the fact that the 2067-68
season was the first in which the total catch was less than
1/1427247692705959881058285969449495136382746624 ton; (158) the fact that the 2068-69 season was the first
in which the total catch was less than 1/2854495385411919762116571938898990272765493248 ton; (159) the fact
that the 2069-70 season was the first in which the total
catch was less than 1/5708990770823839524233143877797980545530986496 ton; (160) the fact that the 2070-71
season was the first in which the total catch was less than
1/11417981541647679048466287755595961091061972992 ton; (161) the fact that the 2071-72 season was the first
in which the total catch was less than 1/22835963083295358096932575511191922182123945984 ton; (162) the fact
that the 2072-73 season was the first in which the total
catch was less than 1/45671926166590716193865151022383844364247891968 ton; (163) the fact that the 2073-74
season was the first in which the total catch was less than
1/91343852333181432387730302044767688728495783936 ton; (164) the fact that the 2074-75 season was the first
in which the total catch was less than 1/182687704666362864775460604089535377456991567872 ton; (165) the fact
that the 2075-76 season was the first in which the total
catch was less than 1/365375409332725729550921208179070754913983135744 ton; (166) the fact that the 2076-77
season was the first in which the total catch was less than
1/730750818665451459101842416358141509827966271488 ton; (167) the fact that the 2077-78 season was the first
in which the total catch was less than 1/1461501637330902918203684832716283019655932542976 ton; (168) the fact
that the 2078-79 season was the first in which the total
catch was less than 1/2923003274661805836407369665432566039311865085952 ton; (169) the fact that the 2079-80
season was the first in which the total catch was less than
1/5846006549323611672814739330865132078623730171904 ton; (170) the fact that the 2080-81 season was the first
in which the total catch was less than 1/11692013098647223345629478661730264157247460343808 ton; (171) the fact
that the 2081-82 season was the first in which the total
catch was less than 1/23384026197294446691258957323460528314494920687616 ton; (172) the fact that the 2082-83
season was the first in which the total catch was less than
1/46768052394588893382517914646921056628989841375232 ton; (173) the fact that the 2083-84 season was the first
in which the total catch was less than 1/93536104789177786765035829293842113257979682750464 ton; (174) the fact
that the 2084-85 season was the first in which the total
catch was less than 1/187072209578355573530071658587684226515959365500928 ton; (175) the fact that the 2085-86
season was the first in which the total catch was less than
1/374144419156711147060143317175368453031918731001856 ton; (176) the fact that the 2086-87 season was the first
in which the total catch was less than 1/748288838313422294120286634350736906063837462003712 ton; (177) the fact
that the 2087-88 season was the first in which the total
catch was less than 1/1496577676626844588240573268701473812127674924007424 ton; (178) the fact that the 2088-89
season was the first in which the total catch was less than
1/2993155353253689176481146537402947624255349848014848 ton; (179) the fact that the 2089-90 season was the first
in which the total catch was less than 1/5986310706507378352962293074805895248510699696029696 ton; (180) the fact
that the 2090-91 season was the first in which the total
catch was less than 1/11972621413014756705924586149611790497021399392059392 ton; (181) the fact that the 2091-92
season was the first in which the total catch was less than
1/23945242826029513411849172299223580994042798784118784 ton; (182) the fact that the 2092-93 season was the first
in which the total catch was less than 1/47890485652059026823698344598447161988085597568237568 ton; (183) the fact
that the 2093-94 season was the first in which the total
catch was less than 1/95780971304118053647396689196894323976171195136475136 ton; (184) the fact that the 2094-95
season was the first in which the total catch was less than
1/191561942608236107294793378393788647952342390272950272 ton; (185) the fact that the 2095-96 season was the first
in which the total catch was less than 1/383123885216472214589586756787577295904684780545900544 ton; (186) the fact
that the 2096-97 season was the first in which the total
catch was less than 1/766247770432944429179173513575154591809369561091801088 ton; (187) the fact that the 2097-98
season was the first in which the total catch was less than
1/1532495540865888858358347027150309183618739122183602176 ton; (188) the fact that the 2098-99 season was the first
in which the total catch was less than 1/3064991081731777716716694054300618367237478244367204352 ton; (189) the fact
that the 2099-00 season was the first in which the total
catch was less than 1/6129982163463555433433388108601236734474956488734408704 ton; (190) the fact that the 2100-01
season was the first in which the total catch was less than
1/12259964326927110866866776217202473468949912977468817408 ton; (191) the fact that the 2101-02 season was the first
in which the total catch was less than 1/24519928653854221733733552434404946937899825954937634816 ton; (192) the fact
that the 2102-03 season was the first in which the total
catch was less than 1/49039857307708443467467104868809893875799651909875269632 ton; (193) the fact that the 2103-04
season was the first in which the total catch was less than
1/980797146154168869349342097376197877515993038197505

APPARATUS AND MATERIAL

Calorimeter:- A great deal of time was spent in constructing a calorimeter that would be suitable for this work. Several different types were tried but the adiabatic type was the one finally used. The difference in temperature of the outer and inner container was never allowed to be greater than 0.05° and very often it was less, and the time during which this difference existed was very short. The time at which the two containers are at maximum difference in temperature is when the bulb containing the gel is broken and the temperature of the liquid in the inner container goes up suddenly. However, by means of a large resistance used as a heating element, the temperature of the outside vessel is brought up quickly so that there is no more than 0.05° difference between the two at any time. All parts inside of the calorimeter were made of glass with the exception of the leads for the inside heating element. These were made of copper of such size as to produce no heat when the current was flowing thru them. These leads were also lacquered to prevent corrosion by the liquids. The heating element in the inside vessel was a piece of platinum about 5 cms. long soldered onto the copper leads.

The outside of the calorimeter was an earthen-



were jar about 16 inches tall and 10 inches in diameter. Inside of this jar was an inverted bell-jar. The space between these two vessels was filled with saw-dust and the top of the saw-dust filling was covered with a coating of paraffin to prevent an air current. This vessel was covered with a round piece of one inch board which fitted over the top very tightly. Thru this cover was a two inch hole in the center to allow the stirrer and the thermometer of the inside container to project out of it. There was also a hole for the stirrer thermometer, and leads for the heating element. Inside of this container was an evacuated Dewar flask about 12 inches tall and $1 \frac{5}{8}$ inches inside diameter. This was supported in the center of the inverted bell-jar and weighed down by means of a heavy lead weight. The space between the Dewar flask and the bell-jar is filled with distilled water.

Preparation of Gel:- The gel used was a product of The Silica Gel Corporation and was of good quality. All samples of gel were first freed of any particles that were brown or discolored in any way and also particles that were of a white color. Only the clear transparent particles being used.

Approximately 2.5 g. samples of the gel were used in all cases. The gel was treated under different

conditions with different experiments, the results being that the different samples under different conditions of treatment giving different values for the heat of adsorption. The samples of gel were placed in glass bulbs which were blown so that the walls became very thin, yet were strong enough to withstand being evacuated. These bulbs were then sealed off from the air with the gel in them.

One experiment was performed with several samples of gel just as the gel was received, that is, without being treated in any way, using water.

Other experiments were done using several samples of gel that had been (1) heated for 24 hours at 120°C., (2) for 4 hours at 250° and evacuated at the same time, and (3), evacuated for 1 hour without heating and combinations of heat and vacuum, the purpose being to get samples of gel with varying water content.

The above experiments were repeated using 0.2 N H_2SO_4 solutions in place of water.

The water used was distilled laboratory water which had been redistilled, and the sulfuric acid solution was made of this water and C.P. H_2SO_4 .

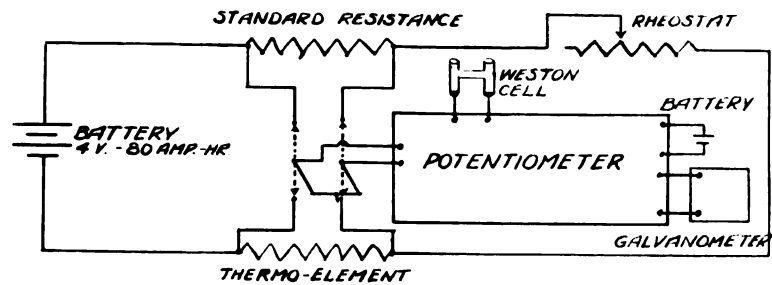
The thermometers used were Bureau of Standards thermometers. The one in the outside vessel being graduated to 0.1°, and the one used on the inside of the Dewar flask being graduated to 0.01°.

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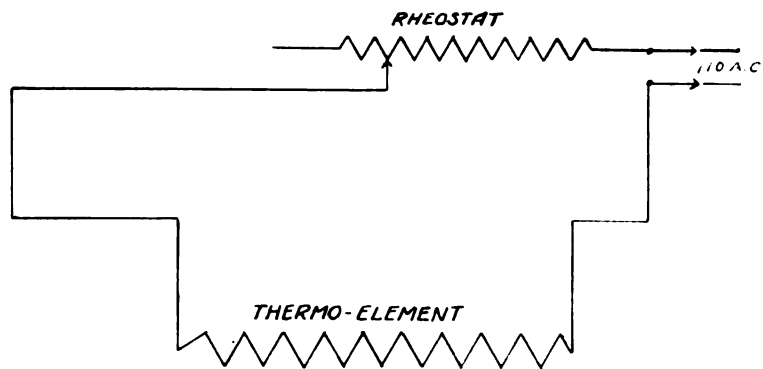
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Method of Procedure:- The liquid whose heat of adsorption was to be determined was put into the Dewar flask. Then the bulb containing the gel was put into the flask and the glass rod with a loop on the end of it was placed over the bulb to hold it down and keep it from getting in the way of the stirrer. Then the stopper with the thermometer, stirrer and thermo-element sealed in it was put into the flask. The flask was then put into the outside bath. The temperature was brought to the temperature of the liquid in the flask either by cooling or heating, as the case may be, during which operation the stirrers in both vessels being in motion. The temperature of the liquid in the flask was then noted and recorded. Then the bulb was broken and the temperature was noted every five seconds by means of a stop-watch until a constant temperature was attained. The time required for this rise in temperature was noted. Then enough heat was introduced into the system to produce the same rise in temperature in the same length of time. This was accomplished by allowing a current from a 4 volt lead storage cell to pass thru a rheostat, a standard resistance and the thermo-element. The current was so adjusted that it would produce the same rise in temperature in the same length of time that the gel did. In this way all losses were corrected. The current was measured

WIRING DIAGRAMS



INSIDE VESSEL



OUTSIDE VESSEL

by noting the potential drop across the standard resistance of 0.1 ohm by means of a type K potentiometer. Then the potential drop across the thermo-element was measured in the same way by throwing the switch in the other direction. Knowing the current and the potential drop, the resistance can be calculated.

Method of Calculating the heat of adsorption:-
Joule's law states that

$$H \text{ (calories)} = \frac{i^2 r t}{4.18} \quad \text{or} \quad H = \frac{E I t}{4.18}$$

Knowing the current, potential drop and the time, the amount of heat introduced into the system can be calculated. Now this gives the number of calories produced by the current and which caused the liquid in the calorimeter to rise the same number of degrees in the same length of time as the gel did. It is necessary to use a current of such value that it will produce the same rise in temperature in the same length of time as the gel, so that losses due to conduction and radiation will be accounted for.

This heat is due to all the gel added. Now to obtain the heat due to one gram of gel or the heat of adsorption of the gel, it will be necessary to divide the total amount of heat by the number of grams of gel used.

$$\frac{H}{g} = \frac{E I t}{4.18g}$$

where g is the number of grams of gel added.

The results obtained are tabulated as follows;

TABLE I

GEL CONTAINS 6.2% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel.
2.5009	22.135	22.510	.375	4.110	.2424	200	47.7	19.07
2.4997	22.160	22.530	.370	4.115	.24278	195	46.6	18.65
2.5003	22.015	22.395	.380	4.230	.2525	180	46.5	18.60
2.5008	22.240	22.830	.390	4.130	.24367	205	49.34	(19.73)
2.5004	22.425	22.802	.373	4.220	.2490	190	47.82	19.13
2.4992	22.557	22.935	.378	4.114	.2427	200	47.75	19.11
2.5002	22.512	22.532	.380	4.112	.2426	200	47.73	19.09
2.5033	22.047	22.435	.388	4.095	.2416	210	48.45	19.35
2.5001	22.725	23.092	.367	4.095	.2416	190	44.95	(17.98)
Average								19.00

TABLE II

GEL CONTAINS 4.2% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.4997	22.460	22.893	.433	4.510	.2660	190	54.5	21.81
2.5007	22.600	23.032	.432	4.511	.2661	190	54.5	21.80
2.5021	22.305	22.745	.440	4.495	.2652	200	56.95	(22.76)
2.5002	23.065	23.510	.425	4.500	.2658	190	54.4	21.76
2.5013	22.655	23.090	.435	4.712	.2760	180	55.98	22.53
2.5008	22.497	22.931	.434	4.710	.2760	180	55.94	22.57
						Average		22.02

TABLE III

GEL CONTAINS 3.7% WATER. WETTING WITH WATER

2.4441	24.080	24.575	.490	4.971	.2925	165	55.89	22.37
2.4521	22.330	22.850	.490	5.101	.3121	150	55.2	22.50
						Average		22.63

TABLE IV

GEL CONTAINS NO WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat gr.	Heat per gr. of gel
2.4297	22.690	23.250	.560	5.526	.3245	170	72.8	29.96
2.4308	21.970	22.530	.560	5.541	.3239	170	74.02	30.33
2.4005	21.200	21.760	.560	5.463	.3224	170	71.6	29.83
2.4132	21.300	21.875	.575	5.023	.2970	200	71.37	29.58
2.4349	21.305	21.870	.565	4.997	.29605	205	72.53	29.79
2.3944	21.850	22.435	.585	5.7075	.3310	160	72.54	30.21
2.3940	21.450	22.036	.586	4.728	.2831	240	74.55	(31.14)
2.3811	22.640	23.220	.58	5.675	.33305	160	73.11	(30.71)
						Average		29.96

TABLE V

GEL CONTAINS 15.5% WATER. SETTING WITH WATER

wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total Heat	Heat per gr. of gel
2.5006	23.133	23.313	.185	2.410	.1422	240	19.70	7.88
2.5038	23.007	23.185	.178	2.673	.1634	190	19.32	7.92
						Average		7.90

TABLE VI

GEL CONTAINS 12.5% WATER. SETTING WITH WATER

wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total Heat	Heat per gr. of gel
2.4406	22.055	22.280	.225	3.705	.2170	140	26.80	10.98
2.4224	22.207	22.430	.223	3.691	.21765	140	23.69	11.07
						Average		11.02

TABLE VII

GEL CONTAINS 12% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.3985	23.910	24.138	.228	3.717	.2181	140	27.15	11.32
2.4002	23.170	23.401	.231	3.718	.2182	140	27.13	11.30
						Average		11.31

TABLE VIII

GEL CONTAINS 8.5% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.3320	22.522	22.825	.303	4.519	.2638	150	42.70	13.29
2.2872	22.465	22.775	.310	4.578	.2652	140	42.55	13.20
						Average		13.24

TABLE IX

GEL CONTAINS 5% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.2339	22.500	22.590	.590	4.485	.2629	150	42.21	18.90
2.2366	22.520	22.913	.393	4.489	.2632	150	42.40	18.96
						Average		18.93

TABLE X

GEL CONTAINS 1% WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.1418	22.340	22.832	.492	5.401	.2993	130	50.10	23.40
2.1459	22.503	22.994	.491	5.410	.35001	120	51.10	23.81
						Average		23.60

TABLE XI

GEL CONTAINS NO WATER. WETTING WITH WATER

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp	Current	Voltage	Time	Total	Heat per
						Sec.	heat	gr. of gel
2.3984	23.288	23.880	.592	4.788	.28615	210	71.12	29.66
2.3980	22.235	22.835	.600	4.785	.28555	220	71.53	29.85
						Average		29.75

TABLE XII

Comparison of Heat of wetting with % Water

Gel + Water	W_H
Percent water	Cal.
None	29.75
1%	23.60
3%	18.93
8.5%	18.24
12%	11.31
12.5%	11.02
15.5%	7.90

TABLE XIII

GEL CONTAINS 15.5% WATER. WETTING WITH .2N H₂SO₄

Wt. of gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of gel
2.4997	21.925	22.108	.183	2.986	.1790	170	21.72	8.71
2.5022	21.105	21.295	.190	4.500	.2699	75	21.71	8.69
						Average		8.70

TABLE XIV

GEL CONTAINS 8% WATER. WETTING WITH .2N H₂SO₄

2.2647	22.480	22.800	.320	3.396	.2272	190	40.23	17.77
2.2939	22.816	23.119	.303	4.495	.2608	150	39.13	17.10
						Average		17.43

TABLE XV

GEL CONTAINS NO WATER. WETTING WITH .2N H₂SO₄

Wt. of Gel used	Initial Temp.	Final Temp.	Rise in Temp.	Current	Voltage	Time Sec.	Total heat	Heat per gr. of Gel
2.4131	23.150	23.710	.56	4.772	.2850	210	68.20	28.30
2.3776	22.340	22.920	.58	5.047	.3006	200	72.58	29.80
						Average		28.55

DISCUSSION

It is a well established fact that water adsorbed on the surface of a solid, such as silica gel, has undergone a thermodynamic change in state and is held on the surface by an enormous force. Some of the early investigators to advance this theory are Jungh⁴, Rose⁵, and Parks⁶. This has been more recently confirmed by Patrick and Grimm¹ and Lamb and Coolidge³ by their data on the heat of adsorption of water.

It is quite apparent that the heat of adsorption is due to a change of concentration of the molecules of the liquid at the surface or in the pores of the gel. This has been recently confirmed by Ewing and Spurway⁷ in their determination of the density of water adsorbed on silica gel. They found that the density of water increased when adsorbed on silica gel up to the value 1.6869 g. of water. They noticed that heat was liberated when the gel was allowed to absorb water, but they did not make any measurements on it. They found a close correlation between the density values for 1.6867 g. and 0.6357 g. of adsorbed water which, they said, indicated one phase of water on the gel. The mean density values for the two larger quantities of adsorbed water are less than the density of liquid water at the operating

temperature, indicating the presence of three phases of water: compressed water, liquid water, and water vapor. This water vapor, they said, exerts only a low vapor pressure; hence, all three forms of water are held on the gel under pressure.

Then by calculations based upon the volume of the adsorbed water in the runs where the silica gel contained 1.6867 g. or 0.6357 g. of water, and a correlation of Bridgeman's compressibility data, it was shown that in these cases the pressure on the adsorbed water was of the magnitude of 750 atmospheres.

Thus, when the molecules of water are compressed at the surface or in the pores of the gel, there is a decrease in the kinetic energy of the molecules. In order to have a decrease in the kinetic energy, heat is liberated which is an increase in the potential energy of the molecules. This is the opposite of such phenomena as latent heat of vaporisation, in which case the molecules are driven farther apart due to the addition of heat to the system and the heat being transformed into kinetic energy of the molecules. The forces acting in this phenomena are the stray fields around the molecules of the wetting substance and the molecules of the substance being wetted. The greater these stray fields, the less the tendency to exhibit this phenomena.

The results given in Tables I to IV inclusive, were obtained with a gel that had a maximum water content of 6.2%. The results indicate that there is a general increase in the heat of adsorption as the water content of the gel is decreased. The results given in Tables V to XI inclusive, show somewhat the same thing. There is a decided increase in the heat of wetting between the gel containing 15.5% water and the gel containing 8.5% water. But there is a large difference in the heat of wetting of the gel with 8.5% and that with 3%. As the water content decreases below 3%, the heat of wetting again increases rapidly until the maximum value is reached. It is interesting to note that the largest rise in temperature took place very shortly after the gel was exposed to the liquid and that this initial rise in temperature was larger and took place more quickly with the gel that had the smaller amounts of water on it. We obtained more nearly a wetting of the gel by the liquid, as indicated by the results given in Tables IV and IX, because when the gel is heated and evacuated, the water is in the gaseous state, and a smaller quantity can be held, and is probably held, on the surface of the gel. Now, when the gel is again cooled, the water becomes liquid and occupies a much smaller volume than when in the gaseous state. This condensation of the gaseous water leaves a

large portion of the surface of the gel with nothing adsorbed on it. This free surface then absorbs the liquid with great rapidity and liberates a large amount of energy. The larger this free surface the greater the amount of energy liberated.

According to Patrick and Grimm¹, in order to get a heat of wetting of 19.22 Cal. per gram of gel it is necessary that the gel exhibit a surface of 6.9×10^7 cm.². which is an enormously large surface. It is evident that the surface energy is therefore sufficient to explain the observed heat effects.

Lamb and Coolidge³ in their determinations on the heat of adsorption of vapors on charcoal have calculated that the amount of carbon disulfide adsorbed on a gram of charcoal is 0.4 cc at atmospheric pressure and about 0.25 cc under a pressure of 37,000 atmospheres. The carbon disulfide was sufficient to fill all the capillaries which had a volume of 0.42 cc. Assuming the capillary area to be 100 square meters and that the thickness of a molecular layer is 1×10^{-8} cm., then the above amount of carbon disulfide if spread over the whole surface would have given a layer 40 molecules deep.

Lamb and Coolidge³ regard the heat effect as due to two factors, the heat of liquefaction of the gas and the heat effect due to further compression of the

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liquid by the adhesive forces of the adsorbent. The latter or net heat of adsorption, is equal to the heat of wetting at the saturation pressure of the liquid.

Harkins and Ewing⁶ have obtained direct experimental evidence of the compression of a layer of liquid adsorbed on a solid in the case of activated charcoal and organic liquids. The attractive forces between the charcoal and the various liquids are shown to be constant and of the order of 30 to 40 thousand atmospheres, in agreement with the findings of Lamb and Coolidge³. It is pointed out that experiments on the internal pressure of the liquids have not succeeded in demonstrating pressures higher than 72 atmospheres.

Harkins and Ewing derive the heat of adsorption of a liquid by a solid from surface energy considerations as follows: If we consider that the solid is immersed in the liquid against air, the net result is that the surface of the solid is replaced by a solid - liquid interface. The heat of adsorption, $-Q_a$, is then equal to the total amount of energy given off in the process when carried out isothermally, E_a , or

$$-Q_a = E_a = E_s - E_i$$

Where E_s and E_i are respectively the total

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energies of the solid surface and of the interface. The heat of adsorption of a liquid on a solid has always been found to be positive, indicating that the total surface of the solid is greater than that of the interface.

Table XII is a summary of the results given in Tables V to IX inclusive.

In Tables XIII, XIV, and XV are given the results obtained by wetting the gel having the indicated water contents with approximately 0.2N sulfuric acid. These results agree very well with those obtained for water and gel having on it the same amount of water. This indicates that the presence of sulfuric acid does not effect the heat of wetting of the gel. The acid was analyzed before and after it was exposed to the gel, and it was found that the concentration increased from 0.19330 before exposure to 0.1986 after exposure. This indicates that water and not sulfuric acid was adsorbed by the gel.

Bartell and Miller⁹ in their work on the adsorption by sugar charcoal of acid and basic dyes say that inorganic acids are but comparatively slightly adsorbed by charcoal because the inorganic anion replaces more feebly the OH^- ion. Inorganic bases are adsorbed scarcely at all, owing to the fact that metals less noble than H do not replace H^+ from Carbon.

Silica gel does not seem to have an affinity for acid radicals much the same as carbon.

An attempt was made to obtain the heat of wetting of silica gel with sodium hydroxide solution but no constant temperature could be obtained which indicated that the alkali reacted with the gel.

SUMMARY

1. Some heats of wetting of silica gel with water were obtained with the gel containing varying amounts of water on it.

2. The heat of wetting increased more rapidly as the amount of water on the gel became smaller, that is, there was a very large increase in the heat of wetting between the gel that had 1% water on it and the gel that had very little or no water on it.

3. The heat of wetting of a 0.2N solution of sulfuric acid was obtained and found to be the same as for water alone.

4. No value for the heat of wetting of sodium hydroxide was obtained because it was thought that the alkali reacted with the gel.

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The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry, no matter how small, should be recorded to ensure the integrity of the financial statements. This includes recording all sales, purchases, and expenses in a timely and accurate manner.

The second part of the document outlines the procedures for reconciling the bank statements with the company's records. It states that the reconciliation should be performed at the end of each month to identify any discrepancies and correct them immediately. This process helps to ensure that the company's cash balance is always up-to-date and accurate.

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The tenth part of the document discusses the importance of maintaining accurate records of all financial transactions. It states that every entry, no matter how small, should be recorded to ensure the integrity of the financial statements. This includes recording all sales, purchases, and expenses in a timely and accurate manner.

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