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Diffusion Characteristics in Building Components of Immiscible Hydrocarbon-Water Mix from Flooding

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Abstract: Stud-wall sections with gypsum wall boards, Oriented Strand Board (OSB) sheathing, concrete blocks and batt insulation were flooded with an oil-water mixture to measure the oil and water absorption by these building materials. The difference between absorption by interior and exterior walls, without or with insulation, was explored. The effect on drying of the retention of the absorbed oil and water was measured. The OSB sheathing was found to both absorb and retain the largest amounts of oil and water. The batt insulation influenced absorption of oil by both the OSB sheathing and the gypsum wall board.

1. INTRODUCTION

Petroleum and oil products can enter floodwaters via a variety of sources such as flood-damaged storage tanks, off-shore oil rigs, vehicles, etc. Oil-type products can disperse swiftly and, due to their water insolubility and density, these pollutants can float on the water's surface. As floodwaters subside, films of insoluble oil products often adhere to building materials. Porous building components such as concrete blocks, gypsum board sheets, wood sheathing and siding, bricks and stucco are particularly subject to oil contamination. The cost to repair oil-damaged buildings has been estimated to be three times the cost of repairing buildings unaffected by oil products [1]. The major features of flooding that impact the extent of damage are the flood depth, duration, and oil-contaminant type and concentration in the floodwater. The type and concentration of potential flood-borne oil contaminants and the nature of the water can influence the diffusion process into building materials. For instance, the water could be saline or possibly contain numerous other contaminants like sewage or toxic chemicals that would be miscible with water.

Gypsum, lime plasters and mortar products are susceptible to water-borne pollutants. Prolonged water exposure will cause the paper to delaminate from the gypsum core of plasterboard. Gypsum wallboard will fall apart if it is bumped before it dries [2]. Lime plasters allow water vapor transmission through the walls, which aids the drying process. Lime mortar will allow cyclical moisture changes in a building without any major cracking [3]. Gypsum, lime plasters and mortar samples have been tested for: (1) heavy metals (e.g., antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); (2) hydrocarbon contamination (e.g., diesel range organics (DROs)); (3) pesticide contamination (e.g., chlordane, alpha-chlordane, gamma-chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, and heptachlor); and (4) PCB (polychlorinated biphenyls) contamination [4].

It was found that interior gypsum board walls dried and maintained flexural strength following flooding. If gypsum board is able to dry completely within an appropriate time it can be restored to preflood condition with cosmetic restoration [5], but limited data is available on exposure of gypsum board to oil and sewage during flooding [5].

Concrete and concrete blocks are also subject to water-borne pollutants. The resistance of concrete to moisture ingress is related to its porosity and the degree of continuity between the pores [6]. Lightweight concrete blocks are susceptible to cracking after a flood due to expansion and shrinkage on wetting and drying [7]. Drying time is essential for all types of concrete blocks including autoclaved aerated concrete blocks; calcium silicate brick; lightweight aggregate concrete blocks; dense aggregate concrete blocks; and common concrete brick [8]. Neutron radiography can be used to determine the height of water and fuel oil absorbed for certain types of concrete [9].

Insulation is also subject to water-borne pollutants. Low water absorptions are likely for extruded polystyrene, expanded polystyrene, and for polyurethane [10, 11]. This closed cell characteristic resists contamination of the insulation. It can be difficult to dry and recover mineral wool and fiberglass batt insulation [7]. Insulation resists contamination by heavy metals, hydrocarbons, pesticides and PCB [4]. Fiberglass batt insulation appears to retain moisture after floods when located in the exterior wall cavities and below the subfloor [5].

Flooding in North Dakota, in which fuel oil contaminated the Red River, led to a study of oil contamination of concrete and wood [12, 13]. Radioactive labeling of hydrocarbons confirmed that the hydrocarbons penetrated deeply into these materials, resulting in hydrocarbon contamination that was difficult to remove. The extent of penetration was related to the concentration of the fuel oil and the time of exposure to the contaminants. The health effects of the hydrocarbon contamination were subtle and often masked. Hence, the problems associated with hydrocarbon contamination of building materials are not fully understood.

The purpose of the current study was to examine the damage done by flood waters contaminated with engine oils. Representative samples were used to identify the extent and location of oil contamination on building materials while wet and dry.

2. EXPERIMENTAL

All specimens were prepared and contaminated at Tuskegee University. The specimens were shipped from Tuskegee University to Mississippi State University for the total petroleum hydrocarbons (TPH) and moisture analyses.

2.1. Materials

Various types of building materials/components were tested for oil contamination. These included 41-cm x 41-cm exterior and interior gypsum wall sections, and 10-cm x 20-cm x 41-cm concrete blocks. The concrete samples were either painted on all four sides, to simulate vertical wicking, or only painted on the two 10-cm x 41-cm sides to simulate both vertical wicking and lateral diffusion of immiscible hydrocarbon –water mix. Two coats of semi-gloss latex were used on the concrete blocks. Also studied were OSB sheathing, wooden studs, and fiber glass batting.

Oil-contaminated flood water was simulated using 0.5% 10W-30 engine oil (by volume) in filtered tap water. The filtered tap water was obtained by passing through a carbon filter and then "aging" in an open container for several days.

2.2. Methods

Contamination: Each material was placed in a five-gallon holding tank that contained the appropriate amount of 10W-30 engine oil. The building materials/components were placed in individual tanks. The filtered tap water was transferred through tubing to the bottom of the tanks to agitate the oil without splashing on the building materials/components. The level of the oil-water mixture was positioned at approximately half the height for each material used. If necessary, the building materials/components were pinned to prevent floating while in the tanks. The building materials/components remained in the tanks for 72 hours. The water stayed at the same level during the test. The oil-water mixture was then removed via transfer tubes. After a five-day period, specimens were taken from each material for analysis; those specimens were labeled "wet" samples. After five weeks, another set of specimens was taken. Those samples were labeled "dry" samples.

Analysis: The total petroleum hydrocarbon (TPH) and water content for each sample was obtained. EPA Method 8015B [14] was used to determine the TPH concentration. Moisture (water) content was measured by using an oven-drying method. The samples for each analysis were obtained as described.

Concrete Blocks: Samples were taken by drilling one cm deep into several locations on front and back sections of above and below the waterline using a carbide drill bit. Paints were removed from painted areas using an electric sanding machine prior to drilling. Collected samples were approximately sand particle size.

OSB Sheathing: OSB was cut using a band saw just above the waterline and then sliced longitudinally to provide equal sections for front and back of above and below the waterline. Representative samples were taken from each section for TPH and moisture content determinations.

Exterior and interior gypsum walls: The same cutting and sampling procedures described above for OSB were used for the exterior and interior wall samples. Stainless steel forceps were used to take samples from wet pasty areas of interior and exterior walls.

3. RESULTS AND DISCUSSION

The qualitative description of the appearances of the various materials tested is noted. Quantitative measurements for total petroleum hydrocarbons (TPH) and moisture in these materials are evaluated. The focus of this discussion is on the quantitative measurements.

3.1. Qualitative Observations

The front of the "wet" and "dry" gypsum boards from an interior wall showed an obvious oil discoloration below the initial water line. The backs of these gypsum boards also showed discoloration below the water line. It should be noted that the "wet" sample was kept in a sealed plastic bag. Considerable wicking and discoloration was noticed at the edge of the samples located adjacent to the studs. The wicking associated with the "wet" sample was about 5-in. above the water line. The wicking, adjacent to the studs, on the "dry" sample was about 3-in. Initial marks indicated that both samples had approximately 5-in of wicking. When the "dry" sample was left in the lab environment, it appears that the drying reduced the extent of the wicking in the vertical and horizontal directions.

For the "wet" and "dry" OSB sheathings that were underneath the house wrap, the "wet" sample was sealed in plastic after testing, while the "dry" sample was exposed to laboratory conditions for 5 weeks. There was clear discoloration below the water line due to the oil contamination. The dry sample was slightly lighter in color below the initial water line. The back of the OSB sheathing had discoloration below the water line; there was no significant difference between the "wet" and "dry" samples.

Concrete blocks painted on two sides with two coats of white latex, after flood testing, were designated as "wet" or "dry". The "wet" blocks remained in the tank for five days after the floodwater was drained and were then sent for TPH analysis. The "dry" blocks were left to dry for approximately five weeks after the floodwater was drained. The 0.5% by volume of oil in the flood water left permanent discoloration in the concrete blocks below the water line. There was also evidence of wicking of about 1-in., characterized by the discoloration above the water line. The "dry" block was noticeably more faded than the "wet" block.

Concrete blocks painted on all sides with two coats of white latex, after flood testing, were also designated as "wet" or "dry" but handled somewhat differently than the blocks painted on two sides. A slice of the "wet" sample was sent to MSU for oil analysis immediately after testing. The "dry" sample was sent approximately five weeks afterwards for analysis. Discoloration was observed below the water line on both blocks. Visual observations of longitudinal cross-sections of these blocks indicated no noticeable discoloration and suggested very little diffusion of oil in the painted blocks.

3.2. TPH and Moisture Measurements

The absorption of engine oil by the various materials studied was related to the nature of the material. Gypsum wallboard is composed of calcium sulphate. Concrete blocks have a similar composition to gypsum. Specifically, concrete blocks are composed of oxides of calcium, silicon, and aluminum. Hence it is not surprising that the TPH analysis results for the interior sides of gypsum walls show that they absorb oil in a manner similar to the concrete blocks (Tables 1-3). In particular, the results for the interior gypsum wall surfaces between studs should be compared to the concrete blocks, since these observations for the gypsum are less influenced by the properties of the stud. For these gypsum samples, the total TPH was 152.0 mg/kg below the water line and 61.0 mg/kg above the water line, for the wet samples. For the concrete blocks painted on two sides, the total TPH was 229 mg/kg below the water line and 118 mg/kg above the water line, for the wet samples. For the concrete blocks painted on all four sides, the total TPH was 258 mg/kg below the water line and 203 mg/kg above the water line, for the wet samples. Assuming that the volatilization rate is somewhat greater for the unpainted gypsum board, the pattern for these results is logical. Certainly, the pattern for the oil absorption by the gypsum and the concrete blocks is similar.

Table 1
Total Petroleum Hydrocarbon (TPH) and Moisture Content for Interior Gypsum Walls

	Wet specimens		*Dry Specimens*	
Sample	*TPH, mg/kg*	*% Moisture*	*TPH, mg/kg*	*% Moisture*
Gypsum, adjacent to stud, above water line (front)	57.0	60	<10	0
Gypsum, adjacent to stud, above water line (back)	<50	41	<10	3
Gypsum, adjacent to stud, below water line (front)	69.0	42	152.0	7
Gypsum, adjacent to stud,below water line (back)	354.0	42	111.0	4
Total	606	185	263	14
Gypsum, away from stud, above water line (front)	61.0	21	58.0	2
Gypsum, away from stud, above water line (back)	<50	28	<10	2
Gypsum, away from stud, below water line (front)	77.0	35	97.0	17
Gypsum, away from stud, below water line (back)	75.0	45	<10	13
Total	213	129	150	34

Table 2
Total Petroleum Hydrocarbon (TPH) and Moisture Content for Concrete Blocks Painted on Two Sides

	Wet specimens		*Dry Specimens*	
Sample	*TPH, mg/kg*	*% Moisture*	*TPH, mg/kg*	*% Moisture*
Concrete block, two sides painted, above water line (front)	66.0	6.8	69.0	0.5
Concrete block, two sides painted, above water line (back)	52.0	6.7	<10	2
Concrete block, two sides painted, below water line (front)	78.0	9.03	74.0	6
Concrete block, two sides painted, below water line (back)	151.0	9.40	60.0	4
Total	347	32	203	12.5

Table 3
Total Petroleum Hydrocarbon (TPH) and Moisture Content for Concrete Blocks Painted on All Sides

	Wet specimens		*Dry Specimens*	
Sample	*TPH, mg/kg*	*% Moisture*	*TPH, mg/kg*	*% Moisture*
Concrete block, all sides painted, above water line (front)	66.0	2	67.0	1.5
Concrete block, all sides painted, above water line (back)	105.0	7.0	75.0	1.5
Concrete block, all sides painted, below water line (front)	127.0	6	83.0	5
Concrete block, all sides painted, below water line (back)	98.0	14.0	50.0	5
Total	461	29	275	13

The oil absorption by the gypsum used in the exterior walls (Table 4) cannot be compared directly to that of the concrete blocks. The exterior wall gypsum is directly touching the batt insulation. It is expected that the absorption of oil by the batt insulation (Table 5) can influence the oil absorption by the exterior wall gypsum. For the exterior gypsum wall adjacent to the batt insulation, the total TPH was 73.0 mg/kg below the water line and 106 mg/kg above the water line, for the wet samples. For the batt insulation, there was no measurable TPH below the water line. Above the water line, the batt insulation had a TPH of 179.0 mg/kg, for the wet sample. Hence, in comparing the oil absorption by the interior and exterior wall gypsum, it can be rationalized that the exterior gypsum board is absorbing oil from the batt insulation.

Table 4
Total Petroleum Hydrocarbon (TPH) and Moisture Content for Exterior Wall Gypsum

Sample	*Wet specimens*		*Dry Specimens*	
	TPH, mg/kg	*% Moisture*	*TPH, mg/kg*	*% Moisture*
Gypsum, adjacent to stud, above water line (front)	83.0	49	86.0	10
Gypsum, adjacent to stud, above water line (back)	471.0	46	<10	15
Gypsum, adjacent to stud, below water line (front)	126.0	51	<10	13
Gypsum, adjacent to stud,below water line (back)	243.0	48	254.0	13
Total	1,089	194	340	51
Gypsum, adjacent to batt insulation, above water line (front)	55.0	46	<10	2
Gypsum, adjacent to batt insulation, above water line (back)	51.0	50	<10	1
Gypsum, adjacent to batt insulation, below water line (front)	73.0	51	52.0	6
Gypsum, adjacent to batt insulation, below water line (back)	<50	52	<10	8
Total	179	199	52	17

Table 5
Total Petroleum Hydrocarbon (TPH) and Moisture Content for Batt Insulation

Sample	*Wet specimens*		*Dry Specimens*	
	TPH, mg/kg	*% Moisture*	*TPH, mg/kg*	*% Moisture*
Above water line	179.0	1	67.0	31
Below water line	<50	90	<10	88
Total	179.0	91	67.0	119

The OSB sheathing consists of wood pieces placed in a cured phenol formaldehyde resin. This material is markedly different than the gypsum, the concrete blocks, and the batt insulation (a glass composition). The wood (cellulose and lignin) and the phenol formaldehyde matrix are somewhat polar organic molecules. Hence, an attraction between the hydrocarbons of the engine oil and the aliphatic parts of the wood and resin would be expected. Other additives are in the engine oil, but the major component is the hydrocarbons. The oil absorption results for the

OSB sheathing are shown in Table 6. Below the water line, the OSB sheathing adjacent to the batt insulation had a total TPH of 501.0 mg/kg, for the wet samples. Also for the wet samples, above the water line, the total TPH was 729 mg/kg for the OSB sheathing adjacent to the batt insulation. It should also be noted that the TPH values for the samples directly touching the batt insulation (the “back” samples) were significantly greater than those not touching the batt insulation (the “front” samples), both below and above the water line.

Table 6
Total Petroleum Hydrocarbon (TPH) and Moisture Content for OSB Sheathing

	Wet specimens		*Dry Specimens*	
Sample	*TPH, mg/kg*	*% Moisture*	*TPH, mg/kg*	*% Moisture*
OSB, adjacent to stud, above water line (front)	388.0	9	191.0	4
OSB, adjacent to stud, above water line (back)	272.0	12	316.0	8
OSB, adjacent to stud, below water line (front)	246.0	38	580.0	19
OSB, adjacent to stud, below water line (back)	507.0	14	293.0	5
Total	1,063	73	1,380	36
OSB, adjacent to batt insulation, above water line (front)	269.0	14	437.0	9
OSB, adjacent to batt insulation, above water line (back)	460.0	13	285.0	10
OSB, adjacent to batt insulation, below water line (front)	172.0	50	304.0	40
OSB, adjacent to batt insulation, below water line (back)	329.0	28	150.0	32
Total	1,230	105	1,176	91

For the OSB sheathing adjacent to studs (Table 6), the total TPH was 753 mg/kg below the water line and 660 mg/kg above the water line, for the wet samples. The “back” sample below the water line had significantly higher oil absorption than the “front” sample below the water line. However, for the samples above the water line, the “front” sample had higher oil absorption. Additionally, the samples adjacent to the studs, above and below the water line, and back and front, respectively (Table 6) had an increase in TPH upon drying. These observations may reflect the relatively high absorption of oil by the OSB sheathing and a corresponding scatter of the data points used for this study. However, OSB sheathing samples adjacent to batt insulation of the above the water line sections showed much higher TPH concentration than below the water line samples. This could be attributed to quickness in adsorption of TPH by batt insulation versus stud in removing most of the mixed oil from the water surface.

3.3. Dry Specimen Analysis

The results for the dry specimens (Tables 1-6) provided insight into the attraction of oil to the various materials. With time, the oil, and the water, will volatilize from a given material. The stronger the attraction of the oil for the material can be correlated with a slower evaporation rate for the oil. A similar correlation can be drawn for the absorption of water by the sample. The percentage change upon drying for each of the samples is shown in Table 7. These results confirm that the OSB sheathing has a stronger attraction for oil than gypsum, batt insulation and concrete blocks. Near the studs, the percent oil in the OSB sheathing increased, possibly reflecting absorption of oil from the studs. In contact with the batt insulation, the percent oil in the OSB sheathing decreased only slightly (4.4%) during the drying period. The largest loss of oil was by the exterior wall gypsum (68.8% and 70.9 %), respectively, for proximity to a stud or the batt insulation. The batt insulation had an oil loss of 62.6%. The concrete blocks, whether painted on two sides or on all sides had an oil loss of 41.5% and 40.3%, respectively. The interior wall gypsum had a significantly different oil loss depending on whether the measurement was adjacent to a stud (56.6%) or away from a stud (29.6%). This implies that the studs may play a role in maintaining oil in the gypsum sample.

The drying of the samples removed water from all except for the batt insulation. In this case, there was a 30.8% increase in the water content. Since the glass (silica) molecular structure of the batt insulation is hydroscopic, this observation implies that there are sites available for water absorption on the wet batt insulation. Further, it appears that the batt insulation may have contributed water to the OSB sheathing. There was only 13.3% loss of moisture in this OSB sample. In comparison, the OSB sheathing in proximity to a stud showed a 50.7% loss of moisture. The loss of moisture was greatest for the interior and exterior wall gypsum (74-92%). The concrete blocks lost somewhat less water (55-61%) than the gypsum. This result still attests to the similarity of the gypsum and the concrete blocks.

Table 7
Effect of Drying Samples on Oil and Moisture Absorption

	Wet		*Dry*		*Change*	
Sample	*Oil, mg/kg*	*Water, %*	*Oil, mg/kg*	*Water, %*	*% oil*	*% water*
Gypsum, interior/adjacent	606	185	263	14	56.6	92.4
Gypsum, interior/away	213	129	150	34	29.6	73.6
Gypsum, exterior/stud	1,089	194	340	51	68.8	73.7
Gypsum, exterior/batt	179	199	52	17	70.9	91.5
OSB, stud	1,063	73	1,380	36	(29.8)	50.7
OSB, batt	1,230	105	1,176	91	4.4	13.3
Batt	179	91	67	119	62.6	(30.8)
Concrete block, painted 2 sides	347	32	203	12.5	41.5%	60.9
Concrete block, painted all sides	461	29	275	13	40.3	55.2

3.4. Comparison of Wet and Dry Specimens

Examining the results for TPH graphically (Figures 1 and 2) gives further insight. Figure 1 shows the similarities of TPH absorption by interior wall gypsum and concrete blocks. In contrast, exterior wall gypsum absorbed significantly more oil than the interior wall gypsum or concrete blocks. This is a reflection of the contact of the exterior wall gypsum with batt insulation. The absorption of oil by gypsum, however, is not strong; drying of the interior and exterior wall gypsum samples resulted in a significant and comparable loss of oil. Concrete behaved similarly upon drying.

Figure 2 demonstrates the oil absorption by the OSB sheathing in comparison to the exterior wall gypsum. While both materials accumulated significant amounts of oil, the sheathing maintained this absorption, presumably because of the attraction of woody material to oil. Wood shavings have been used as oil sorbent during oil spills for this reason. The absorption of oil by the batt insulation (also shown in Figure 2) was relatively small. It is possible that the insulation serves as a conduit for the oil to the OSB sheathing and the exterior wall gypsum. The porosity of the insulation may allow it to function in this manner even though the actual absorption by the batt insulation was relatively small.

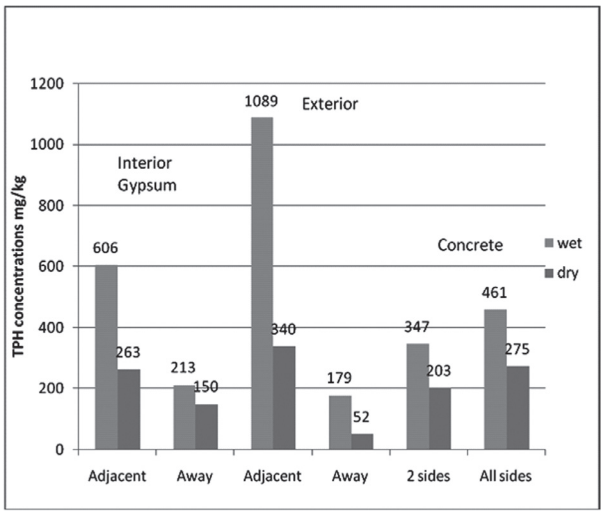

Figure 1: Comparison of Oil Absorption by Gypsum and Concrete Samples

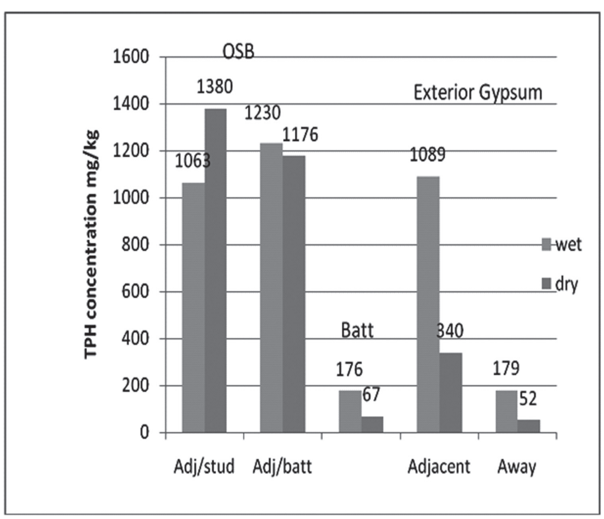

Figure 2: Comparison of Oil Absorption by OSB Sheathing, Exterior Wall Gypsum and Batt Insulation

4. CONCLUSION

Oil and water contamination of building materials can be correlated with the nature of the material. Materials with strong molecular attraction to oil can be expected to absorb relatively larger quantities of oil and retain the oil for longer periods. OSB sheathing has attraction to both oil and water based on the hydrophilic and hydrophobic portions of its structure. Concrete, gypsum and fiberglass batt insulation have much weaker attractions to oil, although the relatively high level of oil in the exterior wall gypsum board of this study implies that batt insulation attraction to oil is less than that for gypsum. Presumably, the oil is transferred from the fiberglass to the gypsum, as well as to the OSB sheathing. These observations can lend themselves to future use of building materials in flood zones.

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