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Performance Evaluation of Hydrophobic Coatings applied on Outdoor Cultural Heritage Building Materials

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ABSTRACT

Conservation of heritage building materials is an important issue and no doubt climatic condition seriously affects the monumental building materials.The surface protection of heritage building materials by water repellent treatment is an essential requirement to control the weathering action of water and other related factors. Recently, with the technological development many new products have been introduced in the market with high claim of their performance as a preservative coat. The protection of cultural heritage buildings and monuments by surface coatings with polymers is a common practice due to their ability to form a protective invisible transparent layer on the surface of monuments and control transport of different fluids from the surface to the monument's interior. Protective coatings are used to make the building material more resistant against deteriorating agents like water, micro vegetation growth and pollutants. To improve the hydrophobicity, now a day's many commercially available masonry water repellents are in practice.

Keywords: *Conservation, Cultural Heritage, Preservative Coat, Hydrophobicity, Deteriorating Agents.*

1. INTRODUCTION

The prevention of deterioration of building materials used in work of art and in construction is of widespread interest. The surface protection by water repellent treatment is an essential requirement to control the weathering action of water and other related factors. The deterioration process of monuments includes the combined action of physical, chemical and biological factors, which induce modifications on the surface and in the structural integrity of the materials [1]. The deterioration of monuments situated in urban area is mainly due to atmospheric pollution [2]. The best way to minimize deterioration of heritage building materials is to prevent water penetration into the building fabric, since accumulation of water is mainly responsible for decay. Recently, with the technological development many new products have been introduced in the market with high claim of their performance as a preservative coat. In nature many plant surfaces, like the leaves of *Nelumbo nucifera* Gaertn, *Colocasia esculenta* L. and *Cotinus Coggygria* Scop. exhibit water repellency due to their textured surfaces with hierarchical micrometer and nanometer sized structures in connection to hydrophobic surface components[3-6]. This remarkable ability of nature has inspired numerous researchers to fabricate surfaces which imitate the surface structure of the superhydrophobic biosurfaces, by using numerous technics and methods, for example, plasma treatment [7-9]., Photolithography[10-11].,casting polymers under controlled conditions or on appropriately designed templates [12-16], sol-gel [17-20], electrospining [21], deposition of nanoparticles on smooth or micro roughened substrates [22-27], deposition of nanoparticle polymer composites on smooth surface [28-31]. In most of the aforementioned studies the generated textured topographies are composed of inherent hydrophilic materials (Young contact angle, $\Theta_Y < 90^0$) and therefore their surfaces are chemically treated to induce hydrophobicity.

Silane and Siloxaneimpregnants were one of the first effective hydrophobic treatments to be used for enhancing heritage building material's impermeability of water and resistance to chemical attacks [32]. Vinyl polymer, polymeric resins, acrylic polymer and fluorinated materials are other examples of protective hydrophobic coatings to heritage buildings surface. Silicate resin is mainly a milky whitish compound, water-based and formed from Silicon and Carbon elements. This compound has a 3-D polymeric structure with Si-O-Si back-bone chains and organic R (alkyl) groups linking with silicon atoms which provide a hydrophobic resistance against water, and high resistance to heat [33,34]. More recently hybrid coatings (Nano-oxides and organic composites) have been also employed. Many hydrophobic materials have been used for surface coating and no single method has been found to be successful on all type of building materials. Many criteria must be met to obtain a high-performance coating, such as reduction of water penetration, good adhesion, durability against mechanical stress and changes - simultaneous fulfillment of all these features is nowadays a challenge.Among the commercially available hydrophobic resins, alkoxy-silanes (silanes) have widely been used as surface coatings. The reactions of these film-forming agents, leading to the formation of network on the surface of the monuments have been recognized [1].

2. MATERIALS AND METHODS

2.1. Materials

In order to evaluate the suitability of a hydrophobic product for surface protection of outdoor heritage mineral building materials it is considered essential to establish a co-relation between the degree of water absorption at low pressure from the treated surface using standard Karsten tube method and water vapor diffusion of the moisture through the treated surface. The degree of protection is a measure to evaluate the characteristic of the water repellent products whereas the water vapour diffusion helps to know the behavior of externally coated composite surface with the same product.

In the present studies five silicone based water repellents Sikagaurd 703W, Silcusil, Wacker BS 290, Protectosil BHN and Wacker SMK 1311 formulations have been selected and their performance have been evaluated on seven substrates (Hyderabad Granite, Hyderabad Sandstone, Chanderi Sandstone, Gwalior Sandstone, Khajuraho Sandstone, Mandu Limestone & Agra Red Sandstone) of different physicochemical nature and origin from various parts of the country with the help of standard test methods. These materials are able to generate hydrophobic coatings and are suggested for the protection of outdoor mineral building materials. As reported in table 2 some are ready to use and some required dilution with a suitable solvent.

2.2. Treatments:

Stone specimens, with dimensions of 5 × 5 × 3 cm3 and 5 × 5 × 2 cm3, were cut by a stone cutter, the samples were smoothened with abrasive paper (180-grit silicon carbide), cleaned in scientific manner by using mixture of 3% solution of ammonia mixed with non-ionic detergent in deionised water with a soft nylon and coir brushes, and rinsed with running water in order to remove dust and other unwanted acretionary deposits. The stone specimens were completely dried in an oven at 60 ◦C, and stored in a desiccator with silica gel (relative humidity (R.H.) = 15%) at 23 ± 2 ◦C. Before the application of the product, the specimens were conditioned in equilibrium with the surrounding environment (24 h in the laboratory, at 23 ± 2 ◦C and 45 ± 5% R.H.). The treatments were performed, on 7 specimens of each dimension, by brush. Physical properties of various samples taken up for the treatment are listed below in table 1.

Table 1: Physical properties of different substrates taken for experimental work

Substrate↓	Specific Gravity (Apparent)	Porosity (Apparent) %	Specific Gravity (True)	Porosity (True) %
Hyderabad Granite	3.03	0.10	3.45	0.12
Hyderabad Sandstone	2.50	3.89	2.66	0.06
Chanderi Sandstone	2.48	5.40	2.70	0.08
Gwalior Sandstone	2.33	8.56	2.56	0.09
Khajuraho Sandstone	2.32	6.85	2.70	0.14
Mandu Limestone	2.54	2.52	2.77	0.09
Agra Red Sandstone	2.64	11.25	2.63	0.004

Different Silicone based products as detailed in table 1 have been evaluated for their comparative performance. The application of all the products was made on all the test samples as per recommended minimum concentrations detailed in table 2. Considering the active ingredient as silicone resin and a review of various studies carried out previously showing their suitability as water repellent, it was considered appropriate to carry out laboratory studies with the product at lower concentrations. The following experimental work was carried out in laboratory for comparative evaluation of untreated and treated samples of size 5 X 5 X 3 cms. And 5 X 5 X 2 cms.

1. Measurement of total Water Absorption at 48 hours.
2. Measurement of water Absorption by Capillarity.
3. Measurement of water vapour permeability.
4. Measurement of water absorption under low pressure (Karsten's tube test).

Table 2: Technical Details of Silicone Based Products

Sl. No.	Product → / Technical Details ↓	Sikagu-ard 703W	Silcusil	Wacker BS-290	Protectosil BHN	Wacker SMK 1311
1.	Physical State	Base- Reddish liquid Activator- Turbid liquid	Colourless clear liquid	Colourless hazy	Clear	Clear yellowish to reddish liquid

2.	Active Substance	Silane-Siloxane	Solvent based silicone coating	Solvent free silicone concentrate based on silane-siloxane	Alkyl trialkoxysilane	Solvent free silicone micro emulsion based on silane-siloxane
3.	Active Content	-	-	100%	94%	100%
4.	Dilution Ratio	100 : 7 Activator : Base	Ready to use	1 : 9 - 1: 15	Ready to use	1 : 9 - 1: 14
5.	Solvent	Water for porous substrate	Ready to use	MTO	Ready to use	Water
6..	Specific Gravity/ Density	-	-	1.05 gm/cm³	7.41 lbs/gal.	0.95 gm/cm³
7.	Curing Time	28 days	28 days	28 days	28 days	28 days
8.	Applicati-on	Brushing wet on wet	Brushing of spraying	Wet on wet brushing	Low pressure spray or brushing	Wet on wet brushing
9.	Manufact-urers	Cantala Industries, Solan, H.P. marketed by Home Care Agency, New Delhi	Hindustan Alkox Ltd., New Delhi	Wacker Metroark Chemicals, West- Bengal	Degussa Master Builders Technology IndiaPvt.Ltd., New Delhi	Wacker Metroark Chemicals, West Bengal

2.3 Experimental Work

2.3.1. Water absorption in 48 hours: Water absorption by total immersion for 48 hours of untreated sample is a measure of the open porosity of the stone. The results of these tests are shown in table 3-a & 3-b as percent (w/w) water absorption for untreated and treated samples after 48 hrs. of total immersion.

Table 3-a: Total water absorption in 48 hours.

Substrate	Hyderabad Granite	Hyderabad Sand stone	Chanderi Sand stone	Gwalior Sandstone	Khajuraho Sand stone	Mandu Lime stone	Agra Red Sandstone
Total water Absorption	0.032	1.55	2.17	3.67	2.95	4.2	4.2

Table 3-b: Imbibition % reduction Water absorption (w/w %) in 48 hours

	Agra Red Sand Stone		Hyderabad Granite		Mandu Lime Stone	
PRODUCT NAME ↓	%	(gm)	%	(gm)	%	(gm)
Sikaguard 703W	4.060	6.040	0.020	0.500	0.710	1.300
Silcusil	4.200	6.290	0.010	0.030	0.750	1.400
Wacker BS-290	4.500	3.140	0.010	0.040	0.780	1.500
Protectosil BHN	4.800	7.110	0.030	0.070	0.750	1.400
Wacker SMK 1311	2.000	3.440	0.010	0.040	0.800	1.500
BLANK	4.500	6.960	0.020	0.060	0.910	1.680
	Chanderi Sandstone		Gwalior Sand Stone		Hyderabad sandstone	
PRODUCT NAME ↓	%	(gm)	%	(gm)	%	(gm)
Sikaguard 703W	1.600	3.08	2.470	4.155	0.799	1.865
Silcusil	2.171	3.345	2.621	4.110	1.601	3.475
Wacker BS-290	0.945	1.775	1.818	2.910	0.570	1.160
Protectosil BHN	1.831	4.36	3.379	5.185	0.782	1.660
Wacker SMK 1311	1.285	2.535	1.383	2.220	0.354	0.780
BLANK	2.120	4.46	3.700	5.920	2.060	2.850
Khajuraho sandstone						
PRODUCT NAME ↓	%	(gm)				

Sikaguard 703W	2.449	3.735				
Silcusil	2.830	4.870				
Wacker BS-290	1.369	2.245				
Protectosil BHN	2.944	4.210				
Wacker SMK 1311	1.726	2.920				
BLANK	2.980	4.910				

2.3.2. Capillary water absorption: To study the behavior of protective substances, capillary water uptake measurements were carried out at different time intervals (24 hours). The results show the effect of concentration of active ingredients of Silicone resin in different substrates as the water uptake is reduced corresponding to this concentration. The comparison of water uptake by capillary action between untreated and treated surfaces is given in the table '4'. Capillary rise rate and weight increase are linear until water reaches the top of the sample.

Table 4: CAPILLARY- Water absorption (ml/cm²) –Agra Red Sand Stone					
TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	7.500	69.375	116.562	150.000	182.180
Silcusil	17.180	171.560	239.060	269.060	289.370
Wacker BS-290	5.000	60.310	98.750	126.560	148.750
Protectosil BHN	44.680	236.560	328.430	359.680	369.375
Wacker SMK 1311	14.370	117.500	149.370	-	-
BLANK	**113.12**	**343.12**	**355.62**	**361.87**	**370.62**

CAPILLARY- Water absorption (ml/cm²) -Chanderi Sand Stone					
TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	3.7500	25.0000	40.0000	47.8125	54.0625
Silcusil	4.0625	43.7500	60.3125	68.1250	71.2500
Wacker BS-290	2.1875	18.4375	39.6875	50.6250	57.5000
Protectosil BHN	3.4375	17.8125	21.5625	27.1875	31.2500
Wacker SMK 1311	4.3700	23.9400	44.0625	54.6875	62.5000
BLANK	**29.3750**	**117.5000**	**150.0000**	**169.3750**	**185.0000**

CAPILLARY- Water absorption (ml/cm²) - Gwalior Sand Stone

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	3.7500	25.0000	40.0000	47.8125	54.0625
Silcusil	4.0625	43.7500	60.3125	68.1250	71.2500
Wacker BS-290	2.1875	18.4375	39.6875	50.6250	57.5000
Protectosil BHN	3.4375	17.8125	21.5625	27.1875	31.2500
Wacker SMK 1311	4.3700	23.9400	44.0625	54.6875	62.5000
BLANK	**29.3750**	**117.5000**	**150.0000**	**169.3750**	**185.0000**

CAPILLARY- Water absorption (ml/cm²) - Khajuraho Sand Stone

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	4.0625	25.9300	39.0600	49.3750	60.0000
Silcusil	5.0000	45.0000	75.6250	101.2500	123.1250
Wacker BS-290	1.8750	22.1875	33.1250	41.8750	47.8125
Protectosil BHN	7.1875	40.3125	84.3750	129.6875	163.7500
Wacker SMK 1311	4.6875	25.0000	38.7500	48.4375	56.8750
BLANK	**62.5000**	**257.5000**	**280.0000**	**283.1250**	**283.7500**

CAPILLARY- Water absorbtion (ml/cm²) -Mandu Lime Stone					
TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	3.4375	26.5625	40.0000	47.8125	54.0625
Silcusil	7.5000	44.0625	60.3125	68.1250	71.2500

Wacker BS-290	1.8750	24.6875	39.6875	50.6250	57.5000
Protectosil BHN	3.7500	15.6250	21.5625	27.1875	31.2500
Wacker SMK 1311	3.7500	28.4375	44.0625	54.6875	62.5000
BLANK	**22.5000**	**83.1200**	**95.6200**	**99.3700**	**96.2500**

CAPILLARY- Water absorbtion (ml/cm²) - Hyderabad Sand Stone

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	2.5000	12.8125	18.4375	24.3750	28.1250
Silcusil	3.4375	13.4375	19.0625	23.7500	25.6250
Wacker BS-290	2.5000	9.0625	13.7500	15.3125	16.5625
Protectosil BHN	3.4375	14.0625	15.3125	18.1250	20.3125
Wacker SMK 1311	2.8100	8.7500	12.1875	14.0625	15.3100
BLANK	106.8750	**158.7500**	**165.0000**	**168.1250**	**171.2500**

CAPILLARY- Water absorbtion (ml/cm²) -Hyderabad Granite

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME					
Sikaguard 703W	1.2500	0.6250	1.2500	1.5625	1.5625
Silcusil	0.3125	0.6250	0.3125	1.5625	1.8750
Wacker BS-290	0.9375	0.9375	1.2500	1.2500	1.2500
Protectosil BHN	1.2500	1.8750	1.2500	1.8750	2.1875
Wacker SMK 1311	0.9375	1.2500	1.8750	2.1875	1.5625
BLANK	**1.2500**	**1.8700**	**1.8700**	**1.8700**	**1.2500**

2.3.3. Water vapour Permeability: The water vapour transmission rate mainly depends on the pore radius, hydrophobic effect of the product and its penetration into the substrate. The water vapour permeability rate was calculated using wet cup method by measuring the wet loss every 24 hrs. For measurement of water vapour permeability rate, each stone sample (5 X 5 X 2 cms.), coated on one side with the preservative was fitted like a plug using silicone sealant into a suitable cup with the little amount of distilled water. The water vapour permeability rate was calculated by measuring the weight loss every 24 hours. The comparison between water vapour flux before and after each treatment allows us to evaluate the reduction of water vapour permeability.

$$P\ \% = \frac{Wut - Wt}{Wut} \times 100$$

Wut = Flux of water vapour through the untreated sample.

Wt = Flux of water vapour through the treated sample at a given time.

2.3.4. Degree of water absorption: The measurement for water absorption at low pressure for treated and untreated samples were carried out by standard Karsten's tube test method at different time intervals up to four days (Table '5'). This test in particular helps to evaluate the water absorption through the treated surface corresponding to the rain driving pressure striking the façade of the heritage buildings. The degree of water absorption (A°) in ml/cm2 between different time intervals may be calculated as follows:

$$A^{o} = \frac{Wt2 - Wt1}{A}$$

Wt1 = Water absorbed after time t1
Wt2 = Water absorbed after time t2
A = Contact area between sample and pipe test.

The results of above calculation and their corresponding charts are exhibited as follows.

Table 5: Water absorption under low pressure (Karsten's tube test method) (Agra Sand Stone

TIME(hrs) →	1	2	3	4	5	6	24	48	72	96
PRODUCT NAME ↓										
Sikaguard 703W	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.270	0.400	0.550
Silcusil	0.075	0.125	0.175	0.250	0.275	0.300	1.400	2.900	5.850	14.770
Wacker BS-290	0.050	0.050	0.050	0.050	0.050	0.070	0.120	0.225	0.350	0.450
Protectosil BHN	0.100	0.100	0.200	0.220	0.320	0.320	1.200	2.550	4.370	6.375
Wacker SMK 1311	0.000	0.000	0.000	0.000	0.100	0.100	0.200	0.400	0.630	0.980
BLANK	**0.200**	**0.400**	**0.500**	**0.700**	**0.800**	**0.950**	**3.300**	**6.900**	**10.600**	**14.300**

Water absorption under low pressure (Karsten's tube test method), Chanderi Sand Stone

TIME(hrs) →	**1**	**2**	**3**	**4**	**5**	**6**	**24**	**48**	**72**	**96**
PRODUCT NAME										
Sikaguard 703W	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.100	0.100	0.150
Silcusil	0.075	0.075	0.100	0.100	0.125	0.125	0.450	0.800	1.250	1.750
Wacker BS-290	0.050	0.050	0.050	0.050	0.050	0.050	0.100	0.075	0.100	0.125
Protectosil BHN	0.050	0.050	0.050	0.100	0.100	0.200	0.200	0.350	0.500	0.650
Wacker SMK 1311	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.100	0.125	0.175
BLANK	0.100	0.100	0.100	0.150	0.350	0.400	0.800	1.400	2.100	2.700

Water absorption under low pressure (Karsten's tube test method) Gwalior Sandstone

TIME(hrs) →	**1**	**2**	**3**	**4**	**5**	**6**	**24**	**48**	**72**	**96**
PRODUCT NAME										
Sikaguard 703W	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.050	0.100	0.150
Silcusil	0.075	0.100	0.170	0.200	0.200	0.250	1.200	2.400	3.600	4.770
Wacker BS-290	0.050	0.050	0.050	0.050	0.050	0.050	0.100	0.200	0.325	0.400
Protectosil BHN	0.075	0.075	0.125	0.150	0.150	0.200	0.750	1.900	2.200	2.970
Wacker SMK 1311	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.125	0.200	0.250
BLANK	0.100	0.200	0.200	0.250	0.300	0.400	0.900	1.700	2.500	3.350

Water absorption under low pressure (Karsten's tube test method) Hyerabad Granite

TIME(hrs) →	1	2	3	4	5	6	24	48	72	96
PRODUCT NAME ↓										
Sikaguard 703W	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025
Silcusil	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.075	0.125
Wacker BS-290	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.050	0.100	0.120
Protectosil BHN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.125
Wacker SMK 1311	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.100	0.100
BLANK	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

CAPILLARY- Water absorbtion (ml/cm²) - Gwalior Sand Stone

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	3.7500	25.0000	40.0000	47.8125	54.0625
Silcusil	4.0625	43.7500	60.3125	68.1250	71.2500
Wacker BS-290	2.1875	18.4375	39.6875	50.6250	57.5000
Protectosil BHN	3.4375	17.8125	21.5625	27.1875	31.2500
Wacker SMK 1311	4.3700	23.9400	44.0625	54.6875	62.5000
BLANK	**29.3750**	**117.5000**	**150.0000**	**169.3750**	**185.0000**

CAPILLARY- Water absorption (ml/cm²) - Khajuraho Sand Stone

TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	4.0625	25.9300	39.0600	49.3750	60.0000
Silcusil	5.0000	45.0000	75.6250	101.2500	123.1250
Wacker BS-290	1.8750	22.1875	33.1250	41.8750	47.8125
Protectosil BHN	7.1875	40.3125	84.3750	129.6875	163.7500
Wacker SMK 1311	4.6875	25.0000	38.7500	48.4375	56.8750
BLANK	**62.5000**	**257.5000**	**280.0000**	**283.1250**	**283.7500**

CAPILLARY- Water absorption (ml/cm²) -Mandu Lime Stone

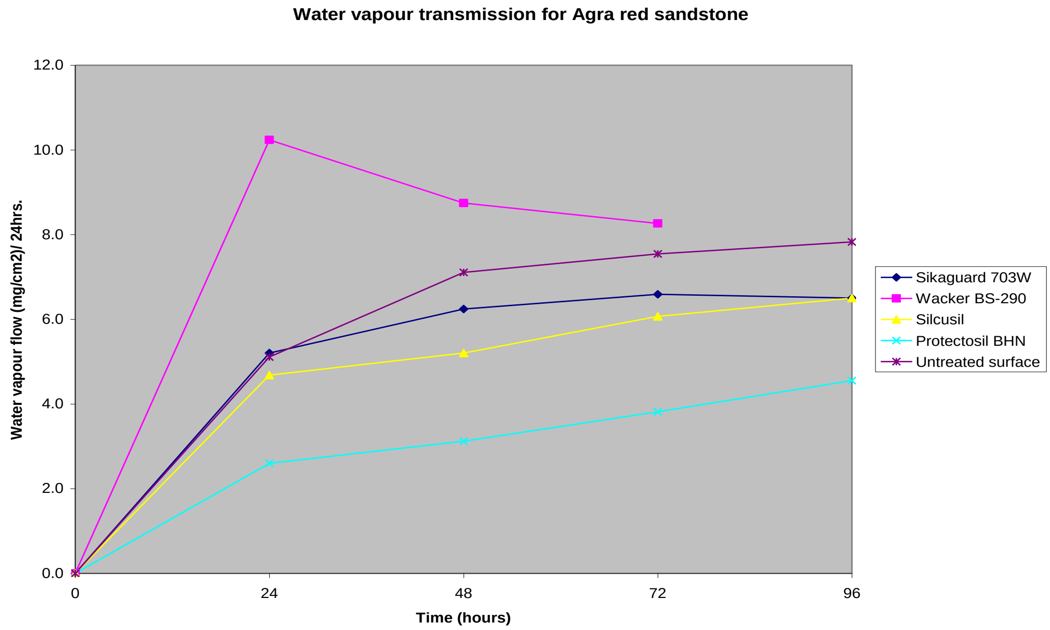
TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	3. 375	26.5625	40.0000	47.8125	54.0625
Silcusil	7.5000	44.0625	60.3125	68.1250	71.2500

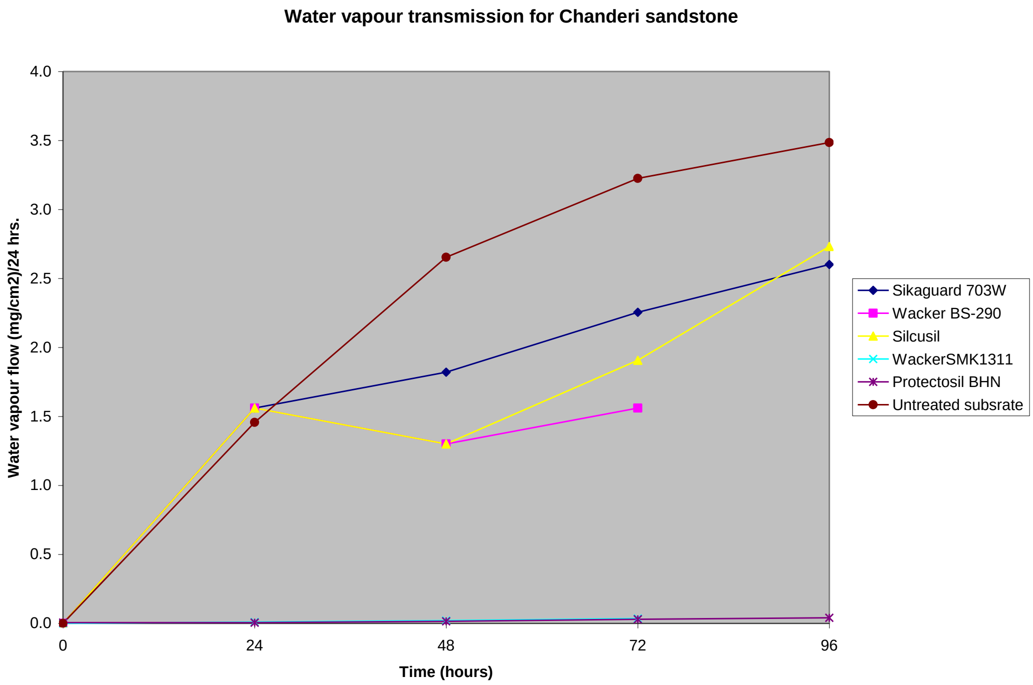
Wacker BS-290	1.8750	24.6875	39.6875	50.6250	57.5000
Protectosil BHN	3.7500	15.6250	21.5625	27.1875	31.2500
Wacker SMK 1311	3.7500	28.4375	44.0625	54.6875	62.5000
BLANK	**22.5000**	**83.1200**	**95.6200**	**99.3700**	**96.2500**

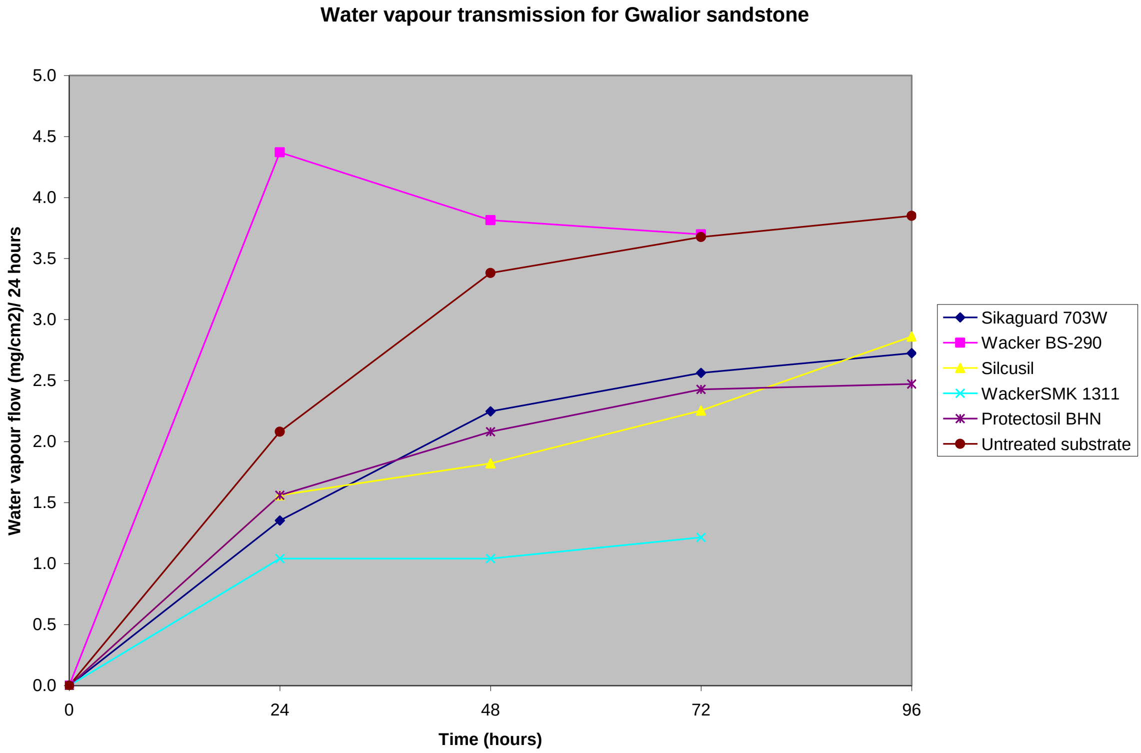
CAPILLARY- Water absorption (ml/cm²) - Hyderabad Sand Stone

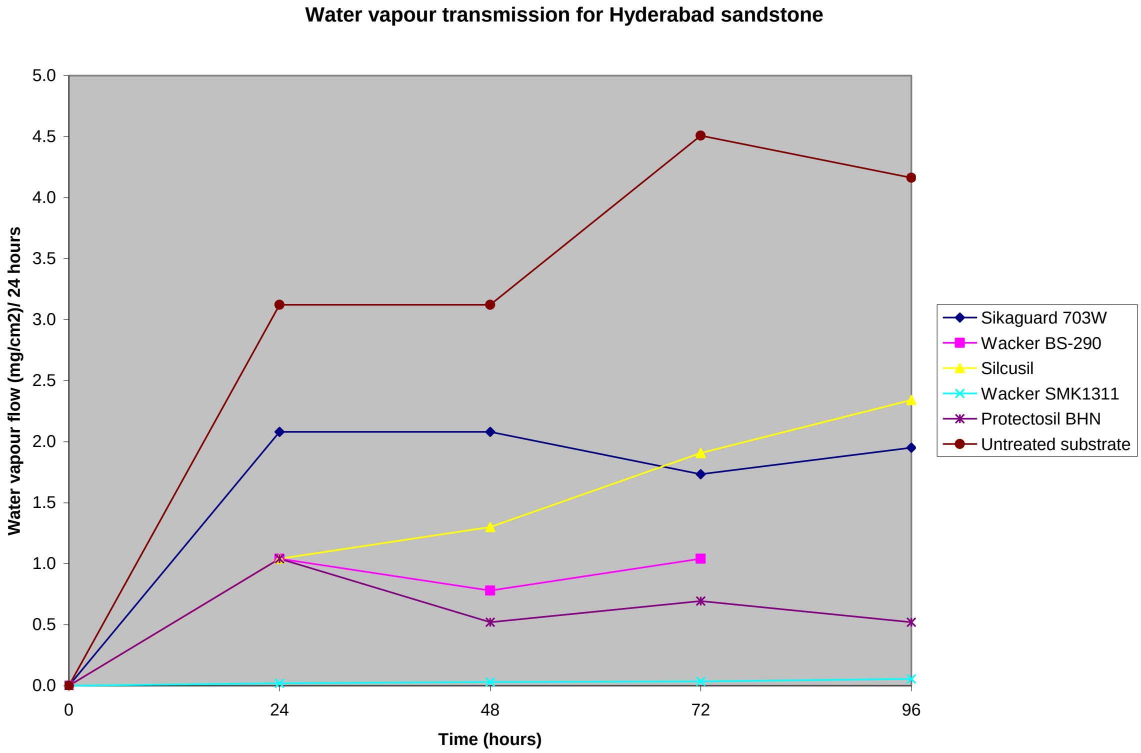
TIME(hrs) →	1	24	48	72	96
PRODUCT NAME ↓					
Sikaguard 703W	2.5000	12.8125	18.4375	24.3750	28.1250
Silcusil	3.4375	13.4375	19.0625	23.7500	25.6250
Wacker BS-290	2.5000	9.0625	13.7500	15.3125	16.5625
Protectosil BHN	3.4375	14.0625	15.3125	18.1250	20.3125
Wacker SMK 1311	2.8100	8.7500	12.1875	14.0625	15.3100
BLANK	106.8750	**158.7500**	**165.0000**	**168.1250**	**171.2500**

Water Vapour permeability Charts for various substrates









Observations:

A Glimpse of the general observation as to ascertain the best and the poorest performances of different products on various substrates is given as below to draw a general conclusion.

a) **Sikaguard 703W2C:**

Capillary water absorption (ml/cm2) by treated Agra red sandstone sample increased gradually from 7.5 to 182.1 and the corresponding degree of protection provided by this product remained at 51% after 96 hours. Whereas the capillary water absorption on Granite stone surface rose to only 1.56 through 96 hours and the PDC% was found to be 16%. The product performance was best seen on the Mandu limestone surface as it absorbed only 54.06 ml/cm2 water through capillary action after 96 hours.

b) **Silcusil:**

Maximum capillary water absorption was observed on the treated surface of Mandu limestone after 96 hours. The values of absorption and % degree of protection were 71.25 ml/cm2 and 25.9% respectively. This product proved least effective on the Granite stone surface.

c) **Wacker BS-290:**

The Agra red sandstone surface was preserved most effectively by this product. The value of maximum capillary absorption was 148.7 ml/cm2. The corresponding percent degree protection was 59.860%. Whereas the least preserved surface was that of Mandau limestone giving 57.50 ml/cm2 and 40.250% as capillary water absorption and PDC% respectively.

***d)* Protectosil BHN plus:**

This product was observed to be least effective on Agra red sandstone surface with 369.375ml/cm2 absorption. However, the Mandu limestone showed maximum prevention from water absorption as only 71.25ml/cm2 was absorbed. The %PDC for this surface was 67.530%.

***e)* Wacker SMK 1311:**

Hyderabad sandstone surface was best protected by this preservative giving a capillary absorption value of 15.31 ml/cm2 after 96 hours along with a protection degree of 91.05%. The behavior of Wacker SMK1311 treated surfaces of Agra red sandstone meets satisfactory criteria as stones preservative. This preservative's performance was not observed to be favorable on the Mandu limestone surface.

***f)* General Physical Observation:**

1) The appearance of the Granite stone cubes turned slightly darker on application of the preservative coatings. This changed appearance could not regain its original form.

2) The Mandu lime stone showed unique structural characteristics with stratified layers visible as minor cracks on the surface of stone cubes. This characteristic might have contributed to the abnormal water absorption, evaporation and vapour transmission behaviors as also evident by the relevant observations.

3) The Sikaguard 703W preservative developed a chalky appearance when applied over the stone cubes. It has an emulsion like physical properties in liquid state.

3. CONCLUSION

Following general conclusions may be drawn based on the observations of a variety of tests conducted on different substrates. The permutation and combinations of different test observations lead to these inferences.

1) The Hyderabad sandstone treated with SMK1311 preservative showed most suitable trend of desired performance in Karsten's tube test, %PDC and Total water absorption.
2) The Mandu Limestone treated with Sikaguard 703W2C gave good results on %Imbibition, Water vapour permeability and %PDC.
3) Wacker BS-290 was found to be most effective on Khajuraho Sandstone in terms of %Imbibition, %PDC and Water vapour permeability.
4) For Gwalior sandstone sample Wacker SMK1311 gave suitable performance in % PDC determination, Total water absorption @ 48 hours and Karsten's tube test.
5) Wacker BS290 preservative applied on Chanderi sandstone gave good performance in %PDC determination, %Imbibition and Karsten's tube test.
6) No preservative was observed to alter the performance behavior of Hyderabad granite stone in these tests hence none of the above preservative coating may be recommended on this substrate.

The products for hydrophobic coatings for outdoor mineral building materials discussed in this paper are actually not reversible in nature and as per norms of archaeological conservation reversibility is a mandatory requirement for materials used in heritage conservation. The preservative coatings which are in practice these days actually not reversible as they remain on the surfaces for a long time after their hydrophobicity is lost and can hardly be removed. Ineffective and aged coatings may jeopardize the building material re-treatability and further conservation interventions. There is utmost important to prepare a formulation for hydrophobic coating having reversible nature.

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