Role of Abrasivity& Cleaning Power of

SILICA

in Toothpastes

Research Project

by

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FOREWORD

As a child, one is told infinite number of times by parents to brush their teeth before going to bed, though kids seldom do. At that age, it becomes a chore rather than a responsibility. It is one of the most cumbersome tasks a child has to perform, brushing ones teeth, and no child has understood the significance thus far. It is always after the painful cavity and a couple of gruesome dental procedures, an individual comes to understand the importance of cleaning once teeth and the impact it has on one's life.

Manufacturers of toothpaste have tried to be creative and imaginative when it comes to manufacturing common toothpaste. The production, marketing and the actual uses have come a long way from the generation where toothpaste was just a toothpaste and not much thought was given besides the few available brands or a couple of flavours. With increase in awareness and hope that consumer will opt for one brand over the other, now manufacturers have not just come out with interesting flavours but also packaging and gimmicks promising "Brighter Smile" compared to its counterparts.

'Toothpaste' and its saga has been part of my upbringing, which is to say is quite unusual for a child growing up. My family's business legacy holds steadfast in manufacturing and developing products mainly for the leading toothpaste industries. When one grows up hearing about products related to the toothpaste, one automatically gets inherited with the need to know and learn more about the business as the conversation around the dining table in a joint family usually involves topics about the new inventions, technologies and raw materials surrounding toothpaste. Then the ladies of the house are encouraged to buy a certain brand over the other and make observations on kid's teeth, the taste, and the outcomes and share their views. It may not be a normal conversation for general families, but it has become the way of life in mine. Thus my curiosity to understand 'TOOTHPASTE' and more specifically the importance SILICA plays in the making of toothpaste, its Abrasivity and the effect it has on the overall cleaning of the teeth.

Through this research paper I plan to investigate the importance of precipitated silica (abrasive silica),which is the most common abrasive used in toothpastes, to help identify future areas of research work that can be undertaken to improve the efficacy of cleaning teeth without damaging the enamel. Therefore, the challenge of cleaning of teeth involves science of making abrasives that can clean the teeth very effectively to remove the bacteria and stain but at the same time it should not damage the teeth and gums which can create other oral problems.

Hence this topic has attracted me to investigate the importance and role of (a) abrasiveness of the particles used in toothpaste and (b) its power of cleaning without damaging the teeth surface. I have particular interest in silica abrasive materials that are frequently used in toothpaste as they are being manufactured by our family business viz. Madhu Silica Private limited. This research paper would help in identifying some future areas of research work that can be undertaken to improve the power of cleaning without damaging of enamel. With this and future researches, I hope to carry the legacy of my family business in innovating new techniques and developing other materials to help in improving the efficacy and use of a ‘common toothpaste’.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to everybody, who has directly or indirectly helped me in making this research study possible.

My grandfather, Mr. R.V. Shah, whose ideologies and foresight to dream big and always look for innovative ideas has made our company, Madhu Silica Pvt. Ltd., one of the leading manufacturers of precipitated Silica in India.

My father, Mr. Darshak Shah, who has been an anchor and a pioneer in developing new products and striving to improve the efficacy and uses of Silica, through his knowledge and ambition.

My school teachers and mentors who have given me guidance and suggestions to conduct the research in the most systematic and authentic way.

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I would like to specially thank our family friends Mrs Shetal Parekh who has been a guide and my mentor.

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RESEARCH PAPER

Role ofAbrasivityand Cleaning Power of Silica in Toothpaste

CONTENTS

SUBJECT	PAGE NO.
1.0 Introduction	1
2.0 Structure of teeth	2
3.0 Nature of Abrasives used in toothpastes and their properties	4
4.0 Measurement of Abrasion (RDA)	6
5.0 Measurement of Cleaning power (PCR)	7
6.0 Silica as abrasive in toothpaste and its properties	8
7.0 Process of silica manufacture	9
8.0 RDA and PCR of commercial grade of silica	12
9.0 RDA and PCR of commercial toothpastes and its correlation	15
10.0 New areas of Innovation in silica abrasives	19
11.0 Summary and Conclusion	20
12.0 References	22

1.0 Introduction

"A clean tooth means a healthy tooth" is a general advice given by most dentists to keep them free of many oral problems. Variety of abrasive agents have been used in toothpaste or toothpowders for many years to clean teeth effectively across the world. Good cleaning of teeth also helps remove tooth stains and restores natural white colour of teeth desired by everybody.

Egyptians were the first one to use abrasive like rock salt, mint powder, dried iris powder and pepper to clean their teeth. Various other abrasive agents like Marble, chalk, ground carbon, ash, pumice, abrasive silica, bark, ground oyster shells, bone ash, alumina powders, oriental herb powder etc. were used to clean teeth before eighteenth century (Ref : Colgate website colgate.com; Thomas Connelly, Huffingtnpost.com)

Prior to the 1850s, tooth cleaning agents were usually available in the form of powders. These were used by finger as bristled toothbrushes were not available. During the 1850s, a new toothpaste in a jar called a Crème Dentifrice was developed and in 1873 *Colgate* started the mass production of toothpaste in jars. *Colgate i*ntroduced its toothpaste in a tube similar to modern-day toothpaste tubes in the 1890s. Nylon based bristled toothbrushes were manufactured in 1938 when E I du-Pont introduced nylon bristles on mass scale.

It is rather surprising to note that the evolution of modern abrasive materials with good cleaning properties that were incorporated in toothpaste happened in nineteenth century after the year 1850.

In the second half of the twentieth century modern toothpastes were developed with scientific abrasive material like precipitated calcium carbonate, calcium phosphate and precipitated silica to provide effective cleaning along with toothbrush with nylon bristles. Toothpastes with very low abrasiveness were also developed to prevent the problems caused by vigorous brushing leading to sensitivity of tooth.

The most recent advances in toothpastes have included the development of whitening toothpastes, in which special abrasive agents like hard silica, alumina and pumice have been introduced to remove the stains that are formed on teeth surface.

During my research work I found that it is a common belief that higher abrasivity means higher cleaning and therefore search for more and more abrasive material continued for cleaning teeth. However, I did not find a direct correlation between abrasivity and cleaning and I felt that this myth needs to be further explored. Dentists have often pointed out the concern on damage of enamel if abrasive materials were increased in toothpaste.As a result of which American Dental Association has put up a limit on maximum amount of abrasives that can be used in a toothpaste.

2.0 Structure of teeth

Regular cleaning of teeth and gums is one of the most important routine activity to maintain proper hygiene of the mouth andhelps prevents many oral problems. Tooth brushing helps to remove food particles stuck in inter-dental areas, which can cause decay with overtime if not removed regularly. Also teeth slowly lose their colour and shine due to formation of stains generally caused by consumption of Tea, Coffee, wine, tobacco etc. thus,brushing teeth with toothpaste that contains cleaning abrasives help to remove these stains and restore the natural whiteness of teeth.

In order to understand the importance of cleaning of teeth regularly, it is necessary to look at the structure of the tooth which is shown below in Fig 1:

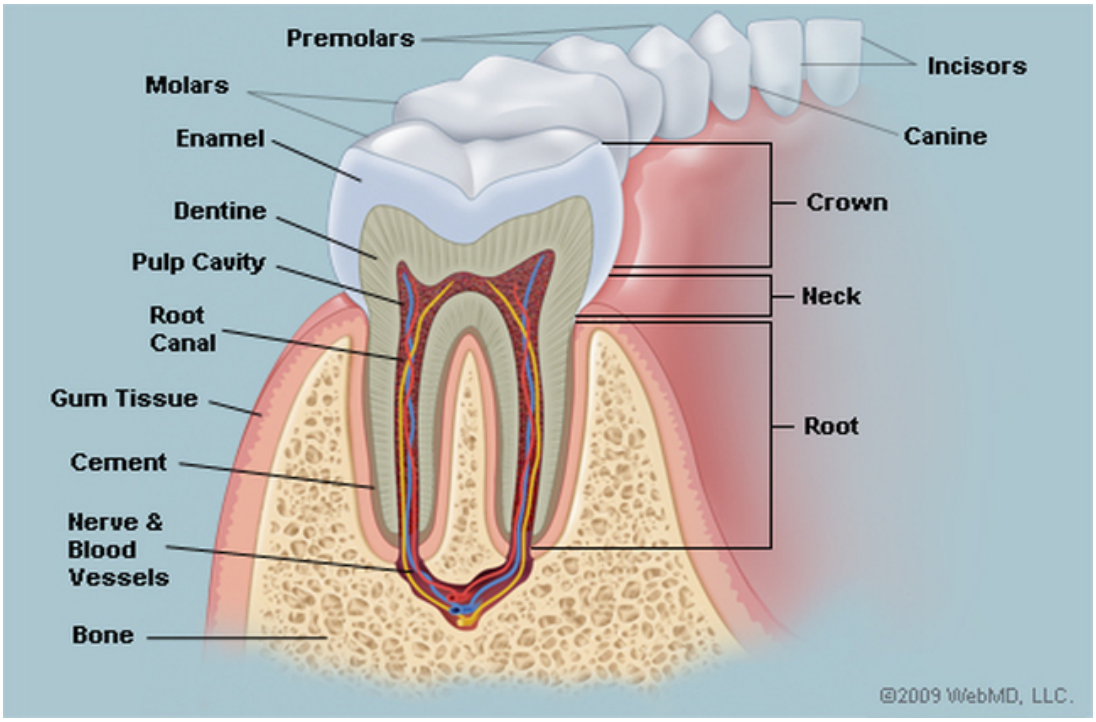


Fig 1: Structure of tooth

The outer layer of tooth consists of enamel which is a hard material consisting of elements like calcium and phosphate in the form of hydroxyapatite. This is inorganic in nature, is very hard and thus primarily helps in biting and chewing. This layer also protects the inside of the tooth structure which is essentially soft. The layer next to enamel is called dentine which is softer in nature and consists of elements like calcium, phosphate and some organic material. This layer is most susceptible to bacterial infections. Below the dentine layer is a pulp layer which contains blood vessels, providing nourishment to the tooth.

There are many types of bacteria present in saliva. These bacteria deposit on the outside surface of enamel and form a sticky film which is called “Plaque”. Plaque is nothing but the film containing bacteria that keep multiplying, if these are not removed effectively. This bacterial film is dangerous as bacteria present in it can ferment the food that we eat, particularly that food that contain sugars or carbohydrates and produce acids. These acids attack the enamel and cause leading to tooth decay. Cavities can be prevented by fluoride present in toothpaste as well as by regular brushing to remove dental plaque.

Therefore, effective removal and prevention of formation of plaque form a

significant part of overall oral hygiene. Plaque is now understood as main causative factor for many oral problems. Tooth brushing with scientifically designed toothpaste in modern times has achieved a certain degree of sophistication both in design of toothbrush and toothpaste to achieve maximum cleaning performance for removal of plaque. Therefore, the most important function of the toothpaste is to remove the plaque very effectively, giving clean teeth, thus providing the protection against bacterial attacks to teeth and gums.

The performance of tooth cleaning is dependent on by (a) toothbrush bristles and (b) abrasives material present in toothpaste.

3.0 Nature Of Abrasives Used In Toothpaste And Their Properties

Abrasive present in the toothpaste, is single most effective component in cleaning the teeth, in conjunction with toothbrush bristles that determines its cleaning power. Abrasive action of abrasive material used in toothpaste is governed mainly by the principles of hard surface cleaning. Abrasive can be defined as a solid particulate material, which when applied under pressure, can dislodge foreign material from the surface. By definition, it should disrupt the surface by its abrasive action on which it acts to remove the debris or deposited material in the surface.

Historically, number of abrasives such as pumice, bone ash, powdered marble, charcoal etc. were used in dentifrices. However, in modern toothpastes, the main abrasives used on the mass scale are precipitated silica, alumina, precipitated calcium carbonate, dicalcium phosphate and natural chalk. These abrasives are characterised by their hardness, Abrasivity and cleaning efficacy.Abrasivity of the material depends on many factors like its hardness, particle size distribution and its shape, and surface roughness of the particles. The optimum combination of these properties would define the Abrasivity of the material.

Hardness: Ideal abrasive material is characterised as having enough harder to give abrasive action but at the same time it should not be harder than the substrate (enamel and dentine) as it would otherwise damage it. As mentioned in the introduction, the tooth consists of outer layer which is called enamel which is very hard but also contains dentine below the enamel which is soft. At the junction of enamel and gums, the dentine can be exposed, hence abrasivity of materials used in toothpastes are defined in reference to softer part which is “Dentine”. The hardness of the material is expressed in units called “Mhos”

which has increasing scale from 1 to 10.Higher number of “Mhos” means the material is harder. For example, talc has scale of 1 while diamond has scale of 10. To appreciate this scale, an example of the hardness value and its Abrasivity as measured on the glass plate of typical abrasives is given below in Table 1:

Table 1 : Hardness of various material used in toothpastes

Abrasive	**Hardness in Mhos**	**Abrasivity on glass lens**
Talc	1	< 1
Gypsum	2	<1
Dicalcium Phosphate	2-2.5	1.4
Ppt. Calcium carbonate	3 -4	3.4
Alumina	3-4	3.4
Calcite	3.5-4.5	4.0
Ppt. Silica	4 -5	5.5
Quartz	7	---
Corundum	9	21.0
Dentine	**4**	
Enamel	**5**	

It is seen from above table that materials like Quartz and Corundum are harder than the enamel and thus should not be used in toothpastes as they may wear off the enamel.

It is most preferred that abrasive material be amorphous, which are soft and do not scratch the surface on rubbing. The particle size and shapes of the abrasive are also important in determining its safety as well as cleaning performance. It is desired that particles of the abrasive used in toothpaste should be small in size, in the range of 2-10 microns and most preferred shape to be spherical to give least scratching on the surface. Particles over 30 micron size are not preferred in dentifrices as they could give rise to high abrasion.

In addition to cleaning, it is desirable for abrasive system to provide polishing of teeth surface to enhance its appearance. It reduces the surface roughness and improves shine on the tooth surface, thus improving the visual appearance of the teeth. Polished surface would have smooth, clean and slick free feel.

4.0 Measurement of Abrasion

Abrasivity of various ingredients used in toothpaste as well as the final product is measured by Radioactive Dentine Abrasion (RDA) method which is a standard recognised by scientists and Dentists all over the world. It is also published and recommended method in International Standard of Dentifrices (ISO/CD 11609, 2007) for toothpastes aswell as in Indian Standard for toothpaste. The outline of its measurement is given below:

(a) *Dentine Specimen*: Human root dentine of extracted permanent teeth are used as substrate. Each set of 8 specimen are irradiated under specified radiation and used for further treatment

(b) *Tooth brushing*: Specimen are mounted in mould resin in the holder of the brushing machine in such a way that part of it protruding above the resin by 2mm. Cross brushing machine is used for brushing using soft brushes immersed in dentifrice slurry with abrasive. The brushing is done for fixed number of strokes

(C) *Radioactivity detector*: The radioactivity of the solution is measured by using specific scintillation detector. The net counting per gram of slurry is measured as net CPM (count per minute) for the sample. The CPM reading is compared with reference material whose RDA is taken as 100 (standard material is calcium pyrophosphate). The RDA is measured using following formula

RDA= 100x (net CPM for test sample)/(net CPM for reference sample)

It may be noted here that RDA is measured using softer material i.e., dentine and not enamel due to safety considerations of not wearing out exposed dentine which is common in many persons. Hence extra safety has been built in defining these RDA numbers.

Higher the value of RDA means it is more abrasive in nature. The RDA range employed in toothpaste can be anywhere between 50-250. For example for children toothpaste, toothpaste having low RDA is designed to take care of thin enamel of babies. While for adults, the RDA value for toothpaste is in the range of 100-150. High RDA toothpaste are also marketed for whitening benefits where some person needs to remove stains of smoking and tobacco for which high RDA toothpaste in the range of 150-250 are being marketed.

The maximum allowable RDA for any toothpaste as per American Dental Association recommendation is 250. However, most the dentifrices operate in the range of 100-200 which is considered safe range for regular brushing.

5.0 Measurement of Cleaning Power:

There are many methods reported to measure the cleaning efficacy of toothpaste by measuring the stain removal from tooth pellicle surface using lab model done under simulation conditions. This is called *in-vitro* model of measurement. The method which is most recognised and endorsed by scientists and Dentists is called **Pellicle Cleaning Ratio (PCR).** The method of evaluation of PCR consists of following steps (5) :

(a) *Tooth staining* : Bovine incisors are cut in to 7 x 7 mm blocks are exposed to standard staining solutions for the fixed time and using the specific method.

(b) *Tooth brushing*: Mounted teeth blocks are then placed in tooth brushing machine using soft toothbrush with the head load of 150g using fixed number of strokes. Standard product with pyrophosphate abrasive is also used in the experiment whose PCR value is taken as 100.

(c) *Tooth brightness measurement*: Brightness of the tooth block is measured using Dr. Lange colour difference measuring instrument as per German Industrial Standard DIN 5033. Brightness increment "Y" is noted

Pellicle Cleaning ratio(PCR) – cleaning power is defined as :

PCR = Mean Y increment of test product/Mean Y increment of reference material

PCR for silica is generally measured at 20% loading while for Calcium carbonate, it is measured at 40% loading.

There are many laboratories who measure RDA and PCR of abrasive materials as well as toothpaste. The names and addresses of two common laboratories who measure RDA and PCR used by many toothpaste manufacturing companies are given as follows.

(i) Indiana University – School of Dentistry 415, Lansing Street, Indianapolis, Indiana, 46202, USA

(ii) Missouri Analytical grade laboratory 1820, Delmar Boulevard, St. Louis, MO 63103-1798, USA.

PCR is indicative parameter of cleaning power of toothpaste and this is more important parameter from consumer point of view. If PCR is higher, it means it is able to clean the teeth well and removes stains from it more effectively. Hence I would like to point out that in subsequent chapters I would like to analyse and study this parameter in relation to RDA to check whether there is a direct correlation between the two parameters. Also it would be interesting to find out as how to get the higher PCR without having the concern on damaging the dentine or the enamel.

6.0 Abrasive Silica And Its Properties:

Precipitated silica is a preferred abrasive used in many toothpastes that are currently marketed. It has following key attributes for which it is preferred to be used in toothpaste formulation by most of manufacturers.

(a)*Colour:* Most of the toothpastes are white in colour and silica can be easily opacified to give very white to white colour which is desired.

(b)*Chemical inertness*: Silica has neutral and inert material which does not interfere with most of the actives used in toothpaste so that they remain actives over a long shelf life of the product.

(c)*Abrasivity and Cleaning*: Precipitated silica can be tailored to give the desired RDA in the range of 50-200 by changing its manufacturing process parameters and it has excellent cleaning potential without damaging the enamel of dentine surface.

(d)*Particle size*: Silica can be produced in small uniform particle size in the range of 4-15 microns and it has smooth feeling in the mouth indicating that it is a good cleaner

(e)*Fluoride compatibility*: Fluoride is most important active that is used in most of toothpaste across the world for controlling cavities. As silica is inert in nature, it does not react with soluble fluorides (unlike other calcium based

abrasives) and thus activity of fluoride is maintained for the long time throughout its shelf life. In other words the effectiveness of anti-cavity properties of toothpaste are retained at all times.

(f)*Refractive index*: it has low refractive index in the range of 1.43-1.45, as a result of which, transparent gel type toothpaste can easily be manufactured using liquid phase materials like sorbitol or glycerine which also has the same refractive index. Due to this unique attribute of silica, transparent toothpaste can be prepared by formulating silica in sorbitol or glycerine medium which also have refractive index of 1.44-1.45. If the RI of solid (silica) matches with liquid medium (Sorbitol or Glycerine), the light can pass through the toothpaste ribbon making it look like a transparent product. The RI of all other abrasive materials have high values in the range of 1.5-1.6 and hence cannot be used to gel kind of toothpaste, which are attractive and motivating to use for children and young adults.

(g) Silica also has advantage of not interacting with flavour molecules and therefore the flavour release is also better with silica based toothpastes.

(e) It is compatible with most other actives, like triclosan, zinc & tin salts used in many commercial toothpaste products to give anti-microbial benefits from toothpaste. These actives often help to keep gums healthy.

(f) It is absolutely safe and has no toxic effects whatsoever.

Because if these positive aspects of silica, it is most preferred abrasive system in good quality products, currently being marketed by various manufacturers.

7.0 Process of Silica Manufacture:

Most of abrasive silica is manufactured by precipitation route by neutralising sodium silicate with mineral acid like sulphuric acid, although some of the abrasive silica is also made by gelling sodium silicate with sulphuric acid.

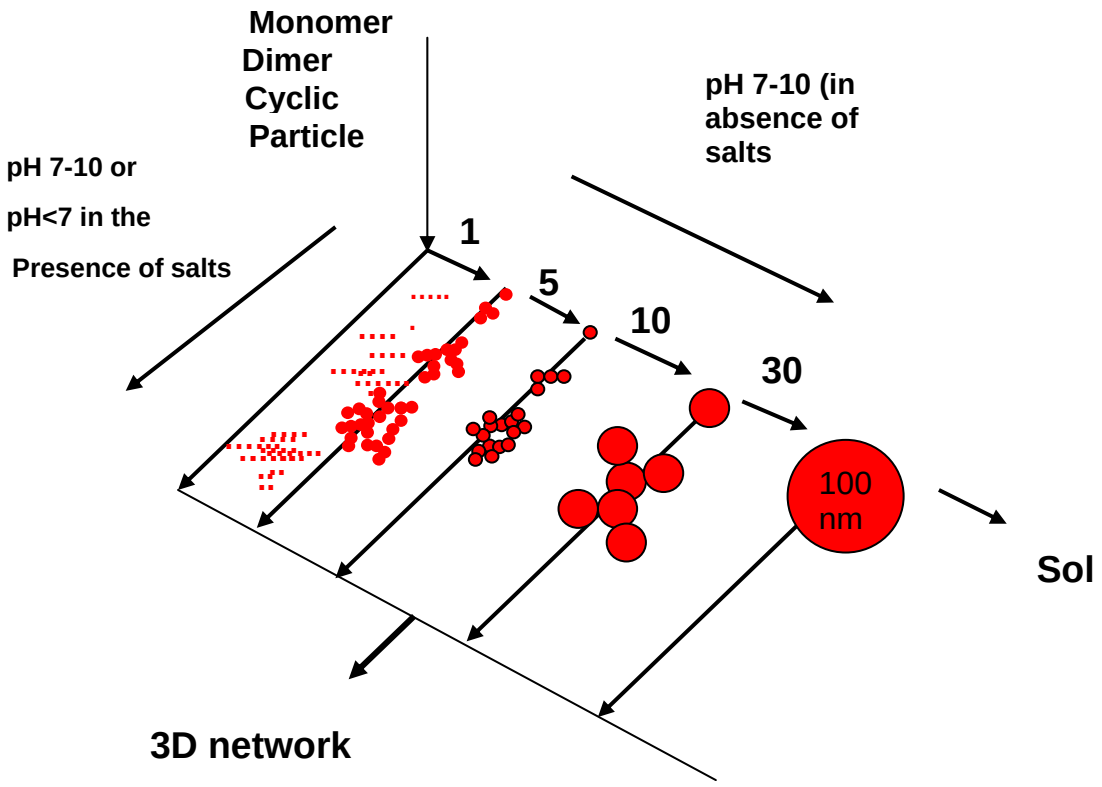
The overall reaction involved in manufacture of silica is represented as follows:

$$Na_2SiO_3 + H_2SO_4 \longrightarrow SiO_2 + Na_2SO_4 + H_2O$$

During the precipitation silica polymerisation takes place rapidly by forming first monomers with rapid growth to large particles. Further linkages take place

between particles to give branched chains and formation of network in the liquid. This is represented in Fig 2.

Fig 2: Polymerisation of silica

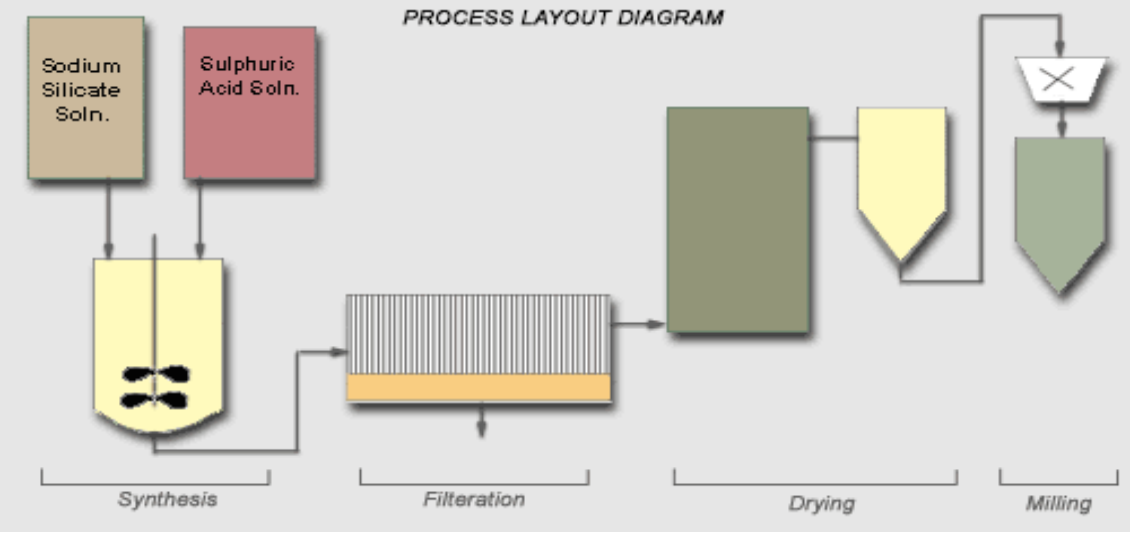


Precipitated silica generally has more open structure and higher pore volume than gel silica. Depending on the precipitation conditions like pH, temperature, dilution and drying conditions, various grades of silica with different surface area, pore volume can be obtained that have different degree of abrasivity and

Precipitated silica generally has more open structure and higher pore cleaning power. These grades of silica are used in different products used by various segments of consumers like babies, adults and senior people as their needs are different. These aspects would be analysed and examined in the subsequent sections to check their suitability for these products.

The simplified process diagram of manufacture of precipitatedsilica is shown below in Fig 3

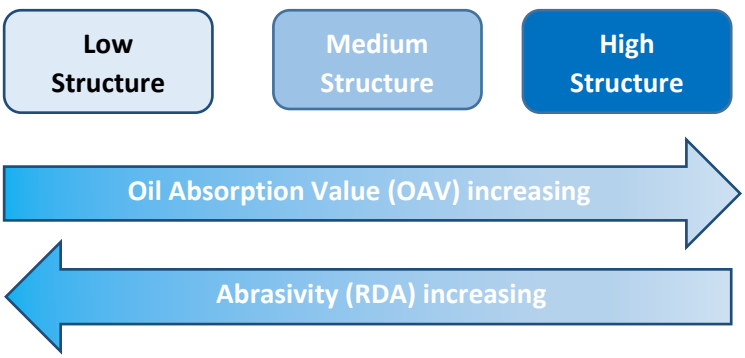
Fig 3 : Process Flow Diagram Of Precipitated Silica Manufacture



It consists of precipitation of silica in agitated reactor, followed by filtration, drying and milling. The most important parameters at the precipitation stage are pH of precipitation, temperature and solid content of slurry. By changing these parameters, one can change the physical properties like surface area, pore volume, bulk density etc. affecting its "Structure"

"Structure" of silica, is defined largely by measuring Oil Absorption Value (OAV). The OAV is measured by the simple technique by adding oil like Linseed oil to dry powder till the mass becomes limpid and movable. Higher the OAV, higher is the structure of silica and similarly low OAV signifies low structure. The structure of silica has considerable bearing on the abrasivity of silica. As the structure decreases, the abrasivity of the material increases and the vice versa as shown in the following Fig. 4

Fig 4: Relationship Between Structure And Abrasivity Of Silica



Based on above approach various grades of silica can be manufactured with different abrasivity having different RDA values.

8.0 RDA and PCR of Commercial Silica Grades:

There are many manufacturers of silica grades with varying RDA and PCR values to suit the end requirement of the product. Toothpaste are positioned to market the product on different end platforms like (a) children toothpaste (b) Gel (transparent) toothpaste for young adults (c) family toothpaste (d) Sensitive teeth toothpaste (e) Whitening toothpaste etc. which highlight different benefits to consumers. These classes of toothpaste require different abrasivity levels in the product. For example toothpaste needed for children and sensitive teeth require low abrasivity to protect the enamel/dentine while whitening toothpaste requires high abrasivity to remove tough stains deposited in teeth.

The following table 2 gives example of various grades of silica of 4 major manufacturers use din various segments along with typical value of RDA and PCR. (9):

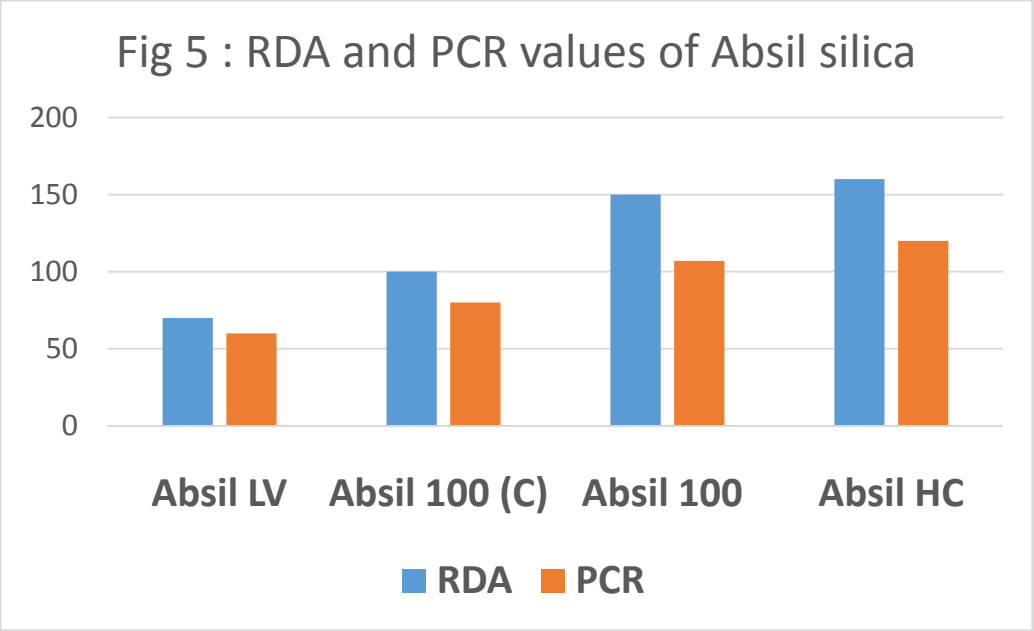
TABLE 2

Product Segment	**Grades of abrasive silica**				**RDA range**	**PCR range**
	Madhu silica, India	**Huber Corp., USA**	**PQ, UK**	**WR Grace, USA**		
Children	Absil 100 L	Zeodent 115	AC 39	Sylodent SM 850C	50-70	60-70
Gel (transparent) toothpastes	Absil 100 (C)	Zeodent 113	AC 35	Sylodent 753	90-100	75-85
Family Toothpaste	Absil 100	Zeodent 124, 119	AC 77	Sylodent 750	140-150	90-100
Sensitive toothpaste	Absil 100 L or 100 (C)	Zeodent 115, 113	AC 36, 35	Sylodent SM	50-100	60-70
Whitening Toothpastes	Absil 200, Absil HC	Zeodent 103	AC 33	Sylodent 756	160-200	110-120

I would now like to focus on various grades of silica manufactured by Madhu Silica (India) which is my area of interest given the proximity of this company with my family.

Madhu silica manufactures ABSIL grade of silica for toothpaste applications which are used in many global toothpaste brands. Absil 100 (C) is commonly used in gel type toothpaste due to its lower refractive index. To get the good transparency.Absil 100 is workhorse abrasive silica that is used in “family” type toothpaste as it has good PCR with reasonable RDA value. Absil HC is special grade silica that has high PCR but also has higher RDA used in ‘whitening’ products as seen from above table.

The RDA and PCR of all silica grades manufactured by Madhu silica are given in the following Fig.5 (measured at 20% loading) as analysed at Indian Lab., USA.

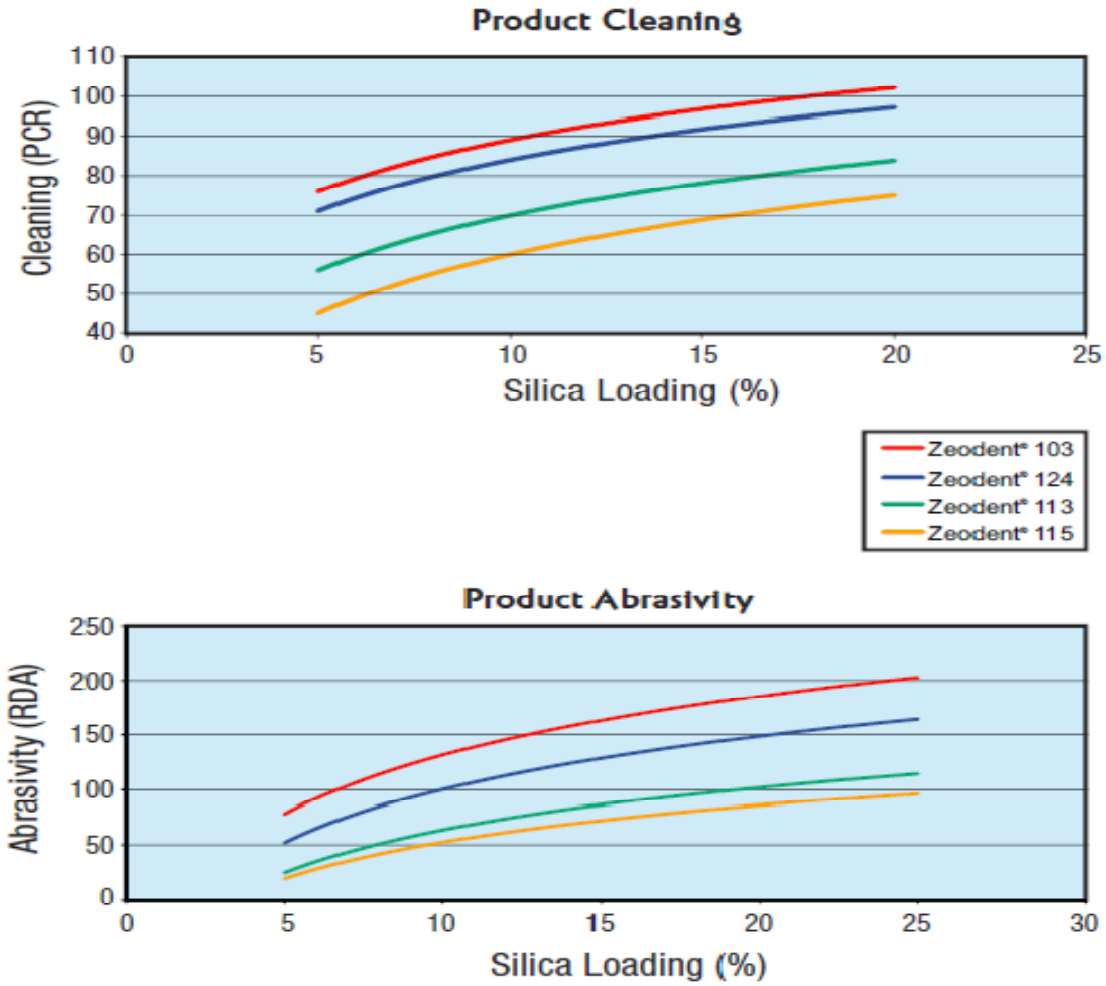


The data in the above chart suggests that PCR value increases with the increase in RDA value. Hence there appears to be some correlation between RDA and PCR values of silica. It is interesting to note that RDA value of all grade of silica is kept below the value of 250, which is maximum value allowed by the American Dental Association.

Both RDA and PCR values depend on the loading of silica in the toothpaste formulation. As the loading of silica is increased, both RDA and PCR values also go up. This is another parameter one can use to adjust the RDA and PCR values in toothpaste by varying the loading of silica in toothpaste. The range of silica loading used in toothpaste generally is in the range of 8-20%. The example of

this is illustrated in the following Fig 6 which shows the relationship between RDA and PCR values, as function of silica loading used in slurry, for Zeodent grade of silica manufactured by Huber Corporation, USA.

Fig 6: Relationship of RDA Vs Abrasive Loading In The Toothpaste



It is seen from the above curves that as the loading of silica is increased, both RDA and PCR increase proportionately. Hence one can select the optimum RDA in the product and design the cleaning efficacy of the product.

9.0 RDA and PCR values of commercial toothpastes:

Considerable amount of data is published on RDA and PCR values of commercial toothpaste prepared form different abrasives (10, 11). RDA and PCR values of various commercial toothpastes are shown in Table 3 and Fig. 7&8 respectively.

TABLE 3

Dentifrices	RDA	PCR	Ratio RDA/PCR
Brite Smile	269	134	2.00
UltraBrite Advanced Whitening	260	140	1.85
Colgate Luminous	258	121	2.13
Crest Vivid White	204	79	2.58
Pearl Drops Triple Action Whitening	195	112	1.74
Aquafresh White & Shine	185	124	1.49
Colgate Total Whitening	165	99	1.66
Rembrandt Plus	165	110	1.50
Crest Pro Health	155	117	1.32
Sensodyne Extra Whitening	150	108	1.40
Crest Extra Whitening	141	101	1.40
Jason's Powersmile	138	81	1.70
Colgate Simply White	135	71	1.90
Mentadent Advanced Whitening	128	80	1.60
GoSmile AM Whitening	119	99	1.20
Aquafresh Extreme Clean	114	100	1.14
Crest Cavity Protection	110	63	1.74
Dentisse Natural Reflection	88	119	0.73
Tom's of Maine Natural	84	63	1.33
Rembrandt Intense Stain	81	99	0.81
Colgate Cavity Protection	76	52	1.46
Supersmile	65	75	0.86
Rembrandt Complete	52	84	0.61
Umbrian Clay	50	54	0.92
A&H Dental Care Advance Cleaning	47	43	1.93
Blanx Whitening	32	24	1.33
Calcium Pyrophosphate Reference Std	100	100	1.0

Fig 7: RDA values of commercial toothpaste

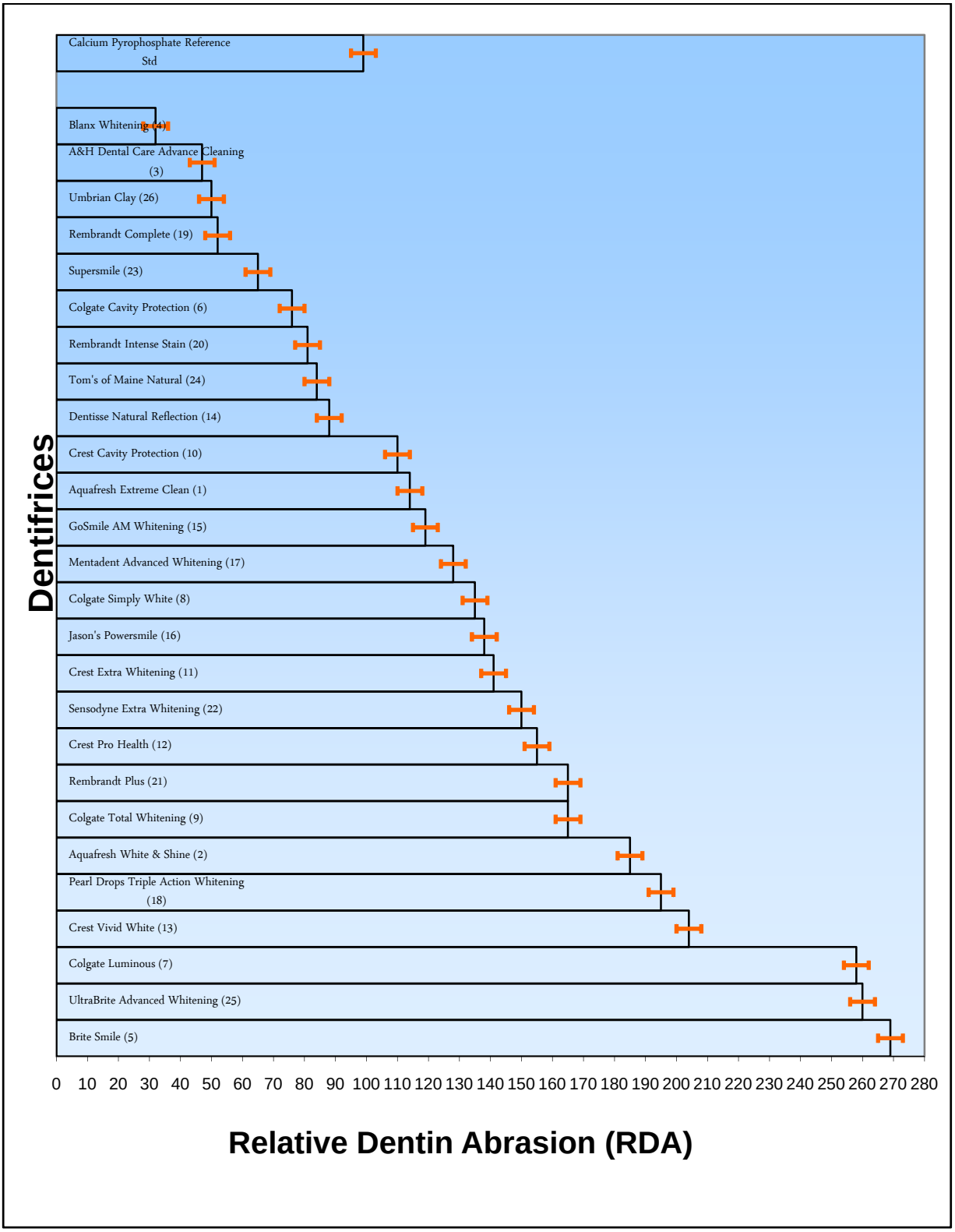
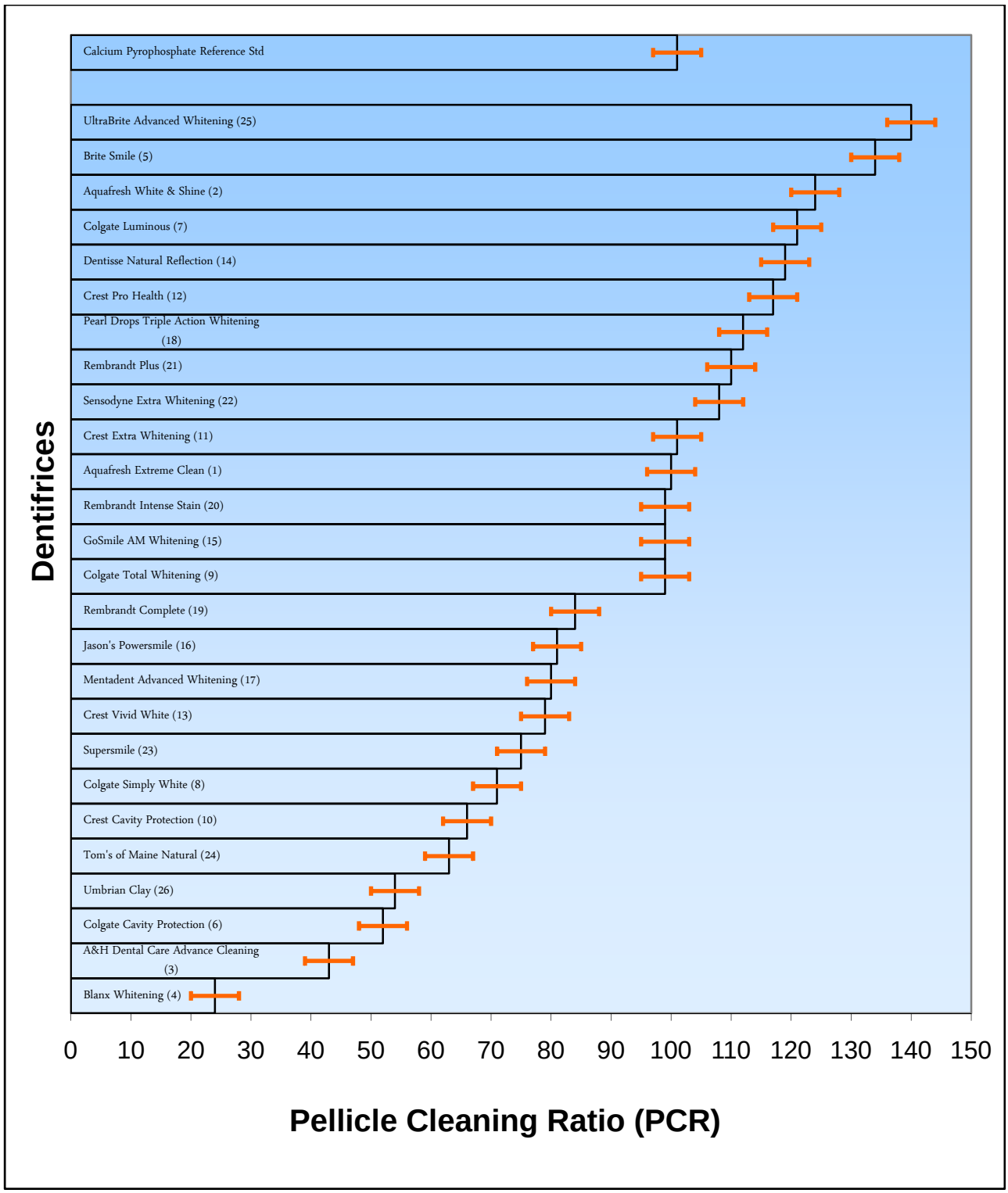


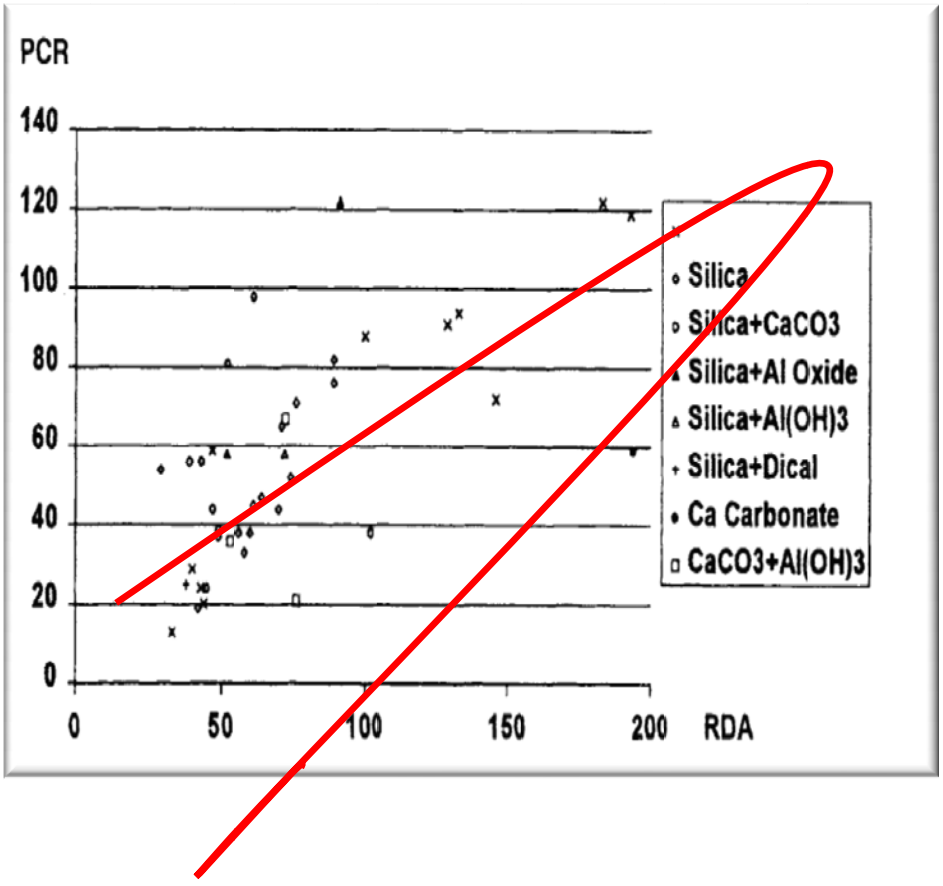
Fig 8 : PCR values of commercial toothpastes



I noticed from the above data that for most of the commercial toothpastes, the RDA value is higher than PCR value. I have also tried to analyse the above data in Table 3 by calculating ratio of RDA/PCR and I found that in most case the ratio is greater than 1 in the range of 1.2- 2.0 for popular brands. Based on above data, one of the observations I have made is that It would be desirable to design the abrasive silica grade that give maximum value of PCR at lower value of RDA. I would like to investigate this aspect further which is based on the logic that PCR is a performance parameter (which needs maximisation) while RDA is a safety parameter (which needs to be minimised) to give best performance of cleaning without any fear of damage to either teeth or gums.

Figure 9 shows the relationship between cleaning and Abrasivity in a two dimensional diagram. The diagram shows that there is no strong correlation for the total measured value but directionally PCR goes up as RDA in increased in linear fashion. It also shows that major anti-stain effects are due to mechanical action or Abrasivity abrasive material used in the product.

Fig 9: Correlation of RDA and PCR Values among European Toothpastes



10.0 New Opportunities in Developing New Grades of Abrasive Silica:

As seen from the data in section 9.0, the value of PCR of most of the commercial silica grades is lower than RDA value. Since my interest in primary in silica abrasive used in toothpaste, I have tried to analyse the ratio of RDA to PCR for various commercial grades of silica mentioned in above chapters. The following Table 4 gives the ratio for RDA to PCR for commercial silica grades manufactured by key companies:

TABLE 4

Grade of silica	Manufacturer	RDA	PCR	Ratio of RDA:PCR
Absil 100 (C)	Madhu	100	85	1.17
Absil 100	Madhu	150	107	1.40
Absil HC	Madhu	180	120	1.50
Zeodent 115	Huber	85	70	1.21
Zeodent 113	Huber	100	85	1.17
Zeodent 124	Huber	150	95	1.57
Zeodent 103	Huber	180	105	1.71
AC 35	PQ	100	80	1.25
AC 77	PQ	150	95	1.57
AC 33	PQ	160	110	1.45

It is noted from the above table that the ratio of RDA: PCR or all key commercial silica grades has been found to be greater than 1 and is in the range of 1.2-1.7. However, from consumer point of view, what is needed is to have maximum PCR at lowest possible RDA so that cleaning of teeth is superior at least erosion of enamel/dentine wear. The erosion of enamel with hard and abrasive materials regular brushing can lead to loss of calcium from outer surface which makes it more vulnerable to acid attack, leading to cavities.

Hence, it is interesting to research and develop silica at affordable price with RDA/PCR ratio of less than one, preferably in the range of 0.7-0.8. This would require different approach to manufacturing silica by precipitation method. Some work has been reported in this direction but these types of materials are not currently available at the affordable price to use them at large scale in

commercial toothpaste products. Hence I would like to emphasize that there is merit in developing new grades of silica at RDA: PCR ratio of less than 1, at the affordable cost so that these can be used in mass market toothpaste products.

Some inventors have developed fused silica with very low RDA but having excellent PCR but these materials are difficult to make and hence these are not found to be commercially attractive. Another approach reported in literature is to develop silica in spherical shape during precipitation which has least abrasivity due to smooth roll over-of surface during brushing. In my opinion, this area of innovation is not fully developed and is worth investigating for the future development.

11.0 Summary and Conclusions:

Metrics for measurements for Abrasivity and power of cleaning of dentifrices have been well established by *in-vitro* techniques in terms of RDA and PCR respectively. There are many abrasive agents used in modern toothpastes but most important of these are Precipitated silica, Precipitated and Natural Calcium carbonate, Dicalcium diphosphate and to some extent Precipitated alumina. Precipitated silica is exclusively used in gel toothpaste due to its lower refractive index as compared to all other abrasives. It is also preferred abrasive by most global manufacturers of toothpastes due to its good cleaning properties as well its inert good properties which do not interfere in stability of other ingredients used in the toothpaste.

Most of the dental silica supplied today have RDA in the range of 50-200 (maximum allowed as per ADA is 250) with corresponding PCR values of 50-150. For regular/family toothpastes, RDA of about 70-150 is maintained in the products while for Whitening toothpaste wherein these are expected to remove hard extrinsic stains, the higher RDA value is in the range of 100-1180 is used by using combination of medium and high abrasive grades. Dentists have opined their concern of using toothpaste products with high RDA values as they have likely potential to cause wear of the enamel, resulting in to dental erosion or damage. Based on this analysis, I feel that the challenge of the industry is to develop dental abrasive materials with low RDA but having higher PCR.

Currently the ratio of RDA to PCR for commercial silica abrasives used in dentifrices is greater than one, having the range about 1.2-1.6. Based on the

detailed analysis done in this project work, I have identified that silica abrasives having RDA to PCR ratio less than 1 would be most preferred to be used in toothpastes, if these are made commercially available at the affordable price. Although some research work is reported in this direction, but commercial grades of silica with RDA to PCR less than one are not available at the price that can be replace the existing grades of silica that are commonly used. In my opinion this area of research can become the basis for developing new grades of silica for the future that would provide excellent cleaning at lower abrasivity as to cause least damage to enamel surface. I feel that it can be further progressed at Madhu Silica to take it forward to the next level.

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