

Pavement Materials
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Lecture No. 21
Bitumen Basics

Hello friends, today we are going to start the third module in the lecture series of pavement materials. In this module, we will be discussing about bitumen. Before we start this module, let us try to understand what is bitumen and where is it typically used in road construction. Bitumen is basically used as a binding agent for the production of what we call as hot mix asphalt or a bituminous mixture. In the bituminous mixture, the binder helps in keeping the aggregate particles together in a dense mass.

Let me show you a typical bituminous mix which is produced in the laboratory, now this I am showing so that before we begin discussing about bitumen, we get a feel of understanding the material so that whenever we are discussing a particular aspect about this material we can recall this particular lecture and try to imagine this material which we see now before the presentation starts.

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This is a bituminous mix which is produced through impact compaction in the laboratory, this mix which you are seeing it comprises of graded mineral aggregates and bitumen. So, the blackish color which this mix has is basically due to the presence of bitumen, in this mix the aggregate particles are kept together through the binding action of bitumen, I also have brought with me today a jar with some bitumen sample.

If you can see here inside this jar is the bitumen, which is now in a semi solid state, if we try to press the bitumen sample inside it will leave a impression of this particular pin which I have used and I hope you are able to see this. Now, this is one of the typical properties of bitumen. If we talk in engineering terms, bitumen is basically a viscoelastic material, what is a viscoelastic material?

Viscoelastic material are those materials the response of which to any given loading condition depends on temperature, depends on the frequency of loading and also depends on the magnitude of the load which we are giving. Most of the times we typically characterize bitumen within the linear viscoelastic region, we will be discussing about this terminologies like linear viscoelasticity as we move forward in the presentation.

When I talk about viscoelastic and when I say that the response of this material is dependent on temperature and the frequency of loading, what do I mean? If you talk about bitumen at lower temperature bitumen acts as an elastic solid, when you increase the temperature of the bitumen, when we start heating the bitumen at very high temperatures typically more than 100 degree Celsius, bitumen mostly behaves like a Newtonian fluid and in the intermediate temperature range and which is the temperature range of in service pavement bitumen mostly behave as a viscoelastic material having some response from the viscous part of the bitumen and some response from the elastic part of the bitumen.

Now, the second parameter is also very important, that is the frequency of loading. Now most of the times it is difficult to imagine what does frequency of loading actually mean. Let us see it through a simple experiment today.

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Here if you see I have a small bitumen sample, now this bitumen sample can be shaped now because it is more of you know in a viscoelastic state, so let us see what happens when I start stretching this bitumen sample. So, please note that I am stretching this sample at a very slow rate now, I am applying a force but very slowly from both the sides.

So, I hope you are able to see the bitumen stretching very slowly, very slowly now and you can see that without any breakage the length of the specimen is increasing, like a typical polymeric material and I can keep pulling it and depending on the properties, this particular sample has a time will come when after stretching the sample will break.

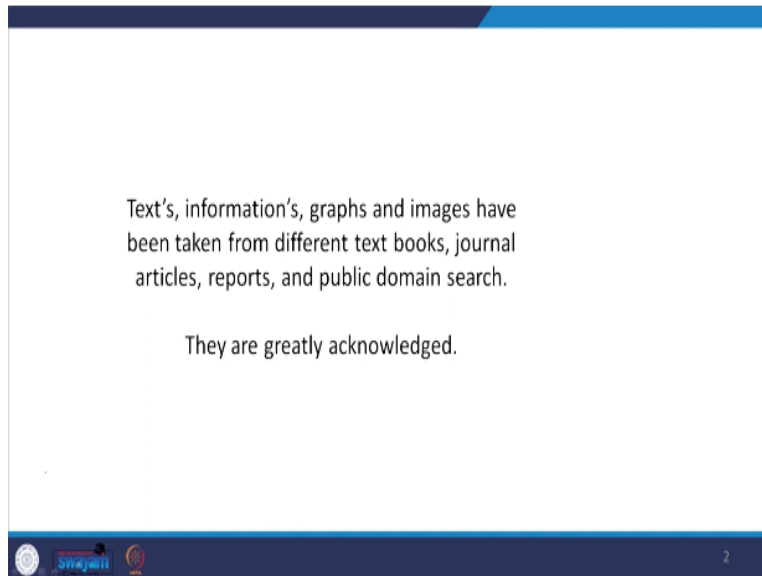
Well, this means that when I am applying the load to the sample at a very low frequency, which means I am basically loading the sample at a very slow rate, there is an inherent elasticity in the material which can be seen, I have rolled the material to the same size as I have shown you initially.

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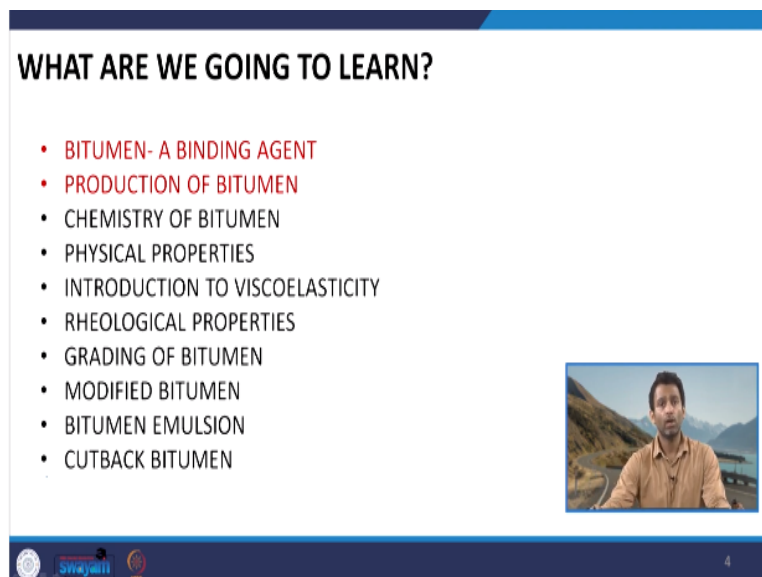
Now, let us see that I apply the load to the material but now I change the rate at which I apply the load, so I will apply a faster rate now to see how the material behaves when I am just pulling it, so this is the material, I am applying it at a very fast rate and you see that when I apply this at a very fast rate the sample fails before stretching to a specific length or before stretching to a higher degree, this shows that the response of this material is dependent on the rate of loading which I am giving to it. With this basic understanding about the feel of the material let us now start this module on bitumen.

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Before we move forward I wish to inform that various text in this presentation information provided, graphs and images shown have been taken from different textbooks, journal articles, reports and general public domain search and they are highly acknowledged.

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So, what are we going to learn in this particular module? In this particular module, we will be discussing about various aspects of bitumen and various uses of bitumen as an engineering material for roadway construction. We will start this module by discussing or by understanding bitumen as a binding agent and we will talk about the production of bitumen.

Then, we will broadly try to understand the molecular composition of bitumen which is a very complicated material, so we will briefly discuss upon this the chemistry of bitumen and then we will talk about in detail

about the physical properties of bitumen and the importance of various physical tests which we carry out in the laboratory.


We will also talk about the general viscoelastic characteristic of the bitumen and the rheological tests and properties, which are studied to understand the viscoelastic phenomena. We will further talk about and discuss about the grading of bitumen and we will complete this module by understanding about modification of bitumen, bitumen emulsion and cut back bitumen. So, today we are going to start this module by discussing about bitumen as a binding agent and understanding the production process of bitumen.

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BITUMEN- A BINDING AGENT

Gwitumen *Pixtuman*
↳
Bitumen

- **Shell Bitumen Handbook:** The term originated in the ancient and sacred language of Hindus in India (“Jatu”)
- **Terminology:** Bitumen (European/Asian countries); Asphalt/Asphalt Binder (North American countries)
- **Definition:** “A tar like mixture of hydrocarbons derived from petroleum, naturally or by distillation, and used for road surfacing and roofing” (Oxford Press, 1996)
- Bitumen is a crude oil product: Most places where you find crude oil are sea beds.
- Mankind’s one of the oldest engineering material



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Very interestingly, the available records states that the term bitumen has been actually derived from the sacred language of Hindus that is Sanskrit and the origin is basically in India where it was referred to as Jatu which means pitch, later on the Latin transformation of this word is Gwitumen or Pixtuman and this was later shortened to bitumen when it passed from French to English and this is what the available record says about the term or the origin of the term bitumen.

Many a times another analogous word of bitumen is asphalt binder and they are mostly used interchangeably, even in our presentation will be using the term bitumen and asphalt binder or asphalt interchangeably. The term bitumen is typically used in European and Asian countries, whereas asphalt or asphalt binder is used mostly in North American countries.

However, it indicates the same material, if we try to find the definition of bitumen we will see that there is no particular or universal definition of bitumen which is available. Different reports, different agencies,

different dictionaries have defined bitumen in their own comfortable way. One of the example is the definition given by Oxford Press 1996 which states that bitumen is a tar like mixture of hydrocarbons which is derived from petroleum, naturally or by distillation and used for road surfacing and roofing.

This particular definition seems to be very interesting because it tells us various aspects about the bitumen, it tells us that bitumen chemically is a hydrocarbon, it also tells us about the origin of bitumen which is petroleum and it can exist in natural form or can be obtained from distillation and it also indicates that bitumen is typically used for road surfacing or for roofing application. Whatever the definition maybe, bitumen is basically a crude oil product, which is obtained from petroleum.

In order to understand the complexity of bitumen, in order to understand the properties of the bitumen, it is important that we briefly discuss about the origin of crude oil and the properties of crude oil. So, if we recall from our textbooks during the school days it used to mention that crude oil which is a fossil fuel is derived from the remains of marine plants and animals and this is not a simple process, this marine plants and animals after the end of their life they settle down at the bottom of the sea.

Subsequently, more plants and animals get deposited at the bottom of the sea and obviously they are mixed up with various other ingredients like mud. Over a period of time and when I say that it is a period of time I am talking about millions of years, so after millions of years of this deposition and bacterial action inside this particular system, radioactive bombardment inside this system, this deposits produces what we call as hydrocarbon of crude oil.

Heat from beneath the earth and pressure which is imposed on this layer from the top later it subjects this crude oil to come out and flow to the top of the surface of earth. Within the surface of earth just beneath the earth if this process has happened, there will be a formation of an oil and gas reservoir, later on this oil and gas reservoirs they are detected through seismic surveys and then this is how the crude oil is obtained and later it is subjected to distillation.

Now, you must be wondering that why we are trying to understand crude oil in this particular lecture. The reason is that bitumen is one of the component of crude oil, now from this definition of crude oil when we try to understand the process the crude oil is formed, you will agree that it is a complicated process, various plants and animals can be present in various deposits of crude oil and since it is not a simple process, the transformation takes millions of years under varying temperature and pressure condition, so each crude oil source is unique in nature and can significantly vary from each other.

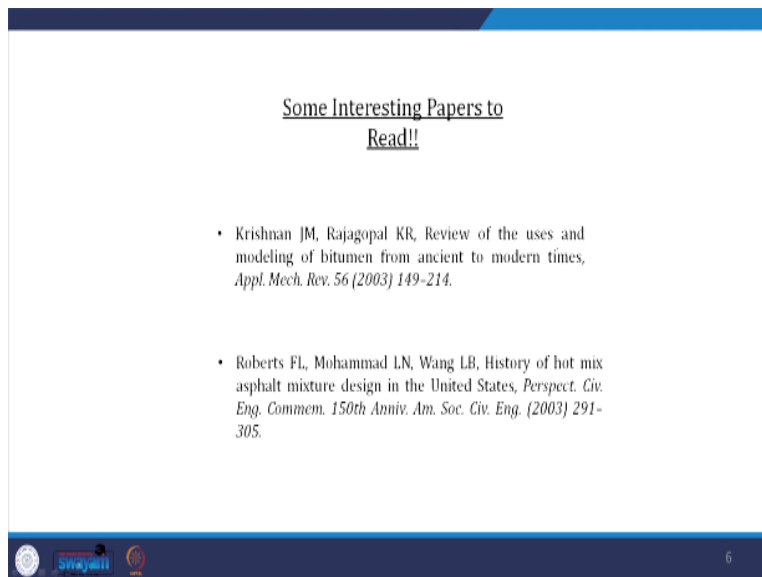
If they significantly vary from each other, therefore the bitumen which is obtained from these sources can also significantly vary and since bitumen is only one of the components there are various other components, so the molecular structure which you see or which will find inside the bitumen is not very

simple to characterize. Crude oil itself contains hundreds and thousands of such molecular orientation which makes this material very complex chemically.

Bitumen is also one of the oldest engineering material, it has been used since we can imagine any civilization started. Long back there are records, there are evidences available that even during 6000 BC the Summarians they used to use bituminous like material for their ship building industry, even in the Indus valley civilization there are evidences of usage of bitumen for construction of large public baths and tanks, even the Egyptians used to use bituminous like material for various purposes like mummification and for building their structures.

Romans who are considered as one of the greatest builders also used bituminous material long back around 2000 BC for the construction of various structures and dams. So, this indicates definitely that the engineering property of bitumen was realized long back in various civilizations and that is what make it a very old engineering material and also a very useful and interesting engineering material.

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Some Interesting Papers to Read!!

- Krishnan JM, Rajagopal KR, Review of the uses and modeling of bitumen from ancient to modern times, *Appl. Mech. Rev.* 56 (2003) 149-214.
- Roberts FL, Mohammad LN, Wang LB, History of hot mix asphalt mixture design in the United States, *Perspect. Civ. Eng. Commem. 150th Anniv. Am. Soc. Civ. Eng.* (2003) 291-305.

History of course is debatable and if some of you are interested to read more about the historical development of bitumen, I would recommend you can go through these two papers which I personally found to be very interesting.

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BITUMEN- A BINDING AGENT

- Bitumen/Asphalt binder used in this lecture will be referred to the residual product obtained from fractional distillation of crude oil in petroleum refinery.
- **Other Binders**
 - **Tar:** Coal or wood are carbonized or destructively distilled in the absence of oxygen: High temperature susceptibility, health hazards like eye and skin irritation.
 - **Petroleum Pitches:** aromatic residues from thermal cracking, coking or oxidation of few petroleum fractions.



In this particular lecture when we will be discussing about bitumen and asphalt binder, we will differentiate this from various other similar binders which have been or are being used for construction. In this particular lecture, bitumen or asphalt binder will be referred to the residual product which we obtain from fractional distillation of crude oil, therefore it is important that we differentiate this particular material from the other form of binders which exist.

One of that binder is tar and many a times people confuse tar with bitumen may be because the physical appearance is almost similar, but we have to realize that tar is a coal or wood derived product and is produced through destructive distillation of coal in the absence of oxygen, tar significantly differs even if we compare its properties with bitumen.

Tar is highly temperatures acceptable in comparison to bitumen and also the fumes which are generated by heating tar are very much health hazardous, especially it causes eye and skin irritation. Bitumen is also different from something which we call as petroleum pitches which are basically aromatic residues obtained from thermal cracking, coking or oxidation of petroleum fractions.

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BITUMEN- A BINDING AGENT

- **Other Binders**

- **Natural/Lake Bitumen:** Trinidad lake asphalt



BITUMEN- A BINDING AGENT

- **Other Binders**

- **Natural/Lake Bitumen:** Trinidad lake asphalt; Gilsonite; Rock asphalt
- Very hard to be used directly: 54% binder, 36% mineral matter, 10% organic matter).
- Used during the last two decades of 19th century.

- **Manufactured bitumen:** Use of bitumen as a binding agent and engineering product took a leap after the beginning of 20th century.

- >100 million tons per year:
 - 85% Roads; 10% Roofing; 5% sealing and insulating



Bitumen can also be present in natural form and this natural form of bitumen are called as natural bitumen or lake bitumen. One of the example of lake bitumen is the Trinidad lake asphalt which is found in the Trinidad island in Venezuela U.S. There are various lakes in this particular island which have different extent of deposit of bitumen and the literature says that one of those deposits is very large with approximately 35 hectares of area and the depth of the bitumen in that lake is approximately 90 meter, which yields more than 10 million tons of bitumen, if you see the total quantity.

This picture shows one of those deposits from the Trinidad lake and you can so clearly see that there is a huge deposit of natural asphalt in this particular lake, so this lake is basically made up of a natural form of bitumen. Gilsonite on the other hand is a natural asphalt, but it is typically found in Utah. Rock asphalt

indicates bitumen impregnated rocks and this has to be mined before they can be actually used for construction purposes, though they are not very popularly used.

One of the famous examples of rock asphalt is the button asphalt found in Indonesia. These natural and lake bitumen they of course cannot be used directly for paving application because on one hand they are not pure in nature, which means they are mixed with various other ingredients. They are also very hard in nature which means you will need a very high temperature to reduce the viscosity of this bitumen and make a workable mix out of it.

If we see the typical composition, the natural bitumen or the lake bitumen has approximately 54 percent binder, 36 percent mineral matter which we have to remove before we can use it for construction and about 10 percent organic matter. So, before its use we have to heat the bitumen to very high temperature of around 163 degree Celsius, so that we also remove the entrapped water, then we have to screen it so that we remove the mineral matter and any other matter which are present in the bitumen and then only we can use the actual bitumen which comes out for construction.

The natural bitumen are presently not being popularly used for construction. After the fractional distillation of crude oil started, but these were used during the last two decades of nineteenth century, when the manufactured bitumen was not available. One of the good examples of construction done using the natural bitumen, specifically the Trinidad bitumen is in 1857 in Pennsylvania, there they made the surface layer of the road using Trinidad bitumen and clean angular sand which they also call as sheet asphalt and this is one of the first bituminous road constructed.

Manufactured bitumen which will be discussing as we move forward is typically used as a popular binding agent and engineering product for the production of bituminous mixtures and its use took an exponential leap specifically after the beginning of twentieth century. Presently, more than 100 million tons of bitumen is produced per year out of which 85 percent of the bitumen are used for road application, 10 percent are used for roofing application and about 5 percent of the produced bitumen are used as sealing and insulating material.

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BITUMEN- A BINDING AGENT



- **Mixtures of bitumen**

- **Cutback and fluxed bitumen:** Viscosity of bitumen is reduced by adding a solvent, normally derived from petroleum, example: kerosene, gas oil, naphtha etc.
- **Bitumen emulsion:** Bitumen particles dispersed in aqueous medium.
- **Modified bitumen:** To change performance properties of straight run bitumen
elastik, long, fence, columns adhesion channels



We also have mixtures of bitumen, here bitumen is the main component but it also contains significant proportion of other materials to meet certain specific requirements. One example of a mixture of bitumen is the cutback and flux bitumen. In cutback bitumen, the viscosity of the base bitumen which we are using is reduced by adding certain solvents which are basically petroleum derived. Solvents such as kerosene, gas oil, naphtha and others can be used to reduce the viscosity of the base bitumen to different degrees.

Cutback bitumen is typically used or I can say was used for spray application for example, as a tack coat or as a prime coat material. After the use of emulsion started in construction industry the use of tack coat as spray application has become less popular. Bitumen emulsion it is a multi phase system, here bitumen particles are dispersed in an aqueous medium and typically the aqueous medium is water and the bitumen particles are kept dispersed and are not allowed to agglomerate or coalesce using certain emulsifiers.

So, these emulsifiers coat the surface of the bitumen, provide a charge to the bitumen particle and these bitumen particles are kept homogeneously dispersed in the aqueous medium. Bitumen emulsion is also used mostly as a spray application and is also used for the production of emulsified bituminous mixtures.

We also have modified bitumen, here we add certain additives to the base bitumen to change the performance characteristics and there can be various performance characteristics we can be dealing with for example, we can change the elastic properties, we can change the temperature susceptibility, we can change the cohesive and adhesive characteristics of the base bitumen, depending on our specific target.


A very popular example of modified bitumen is a polymer modified bitumen where we add polymers to the base bitumen to enhance the rheological characteristic when I say enhanced different types of

polymers contribute towards different form of enhancement, some polymers can significantly increase the elasticity of the base bitumen. You can see a typical example of a polymer modified bitumen and you can see how significantly this bitumen can be stretched and the elastic properties is improved.

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PRODUCTION OF BITUMEN

- Bitumen is **one of the components** produced from **distillation of crude oil**.
- **Bitumen yield** is a function of the parent crude oil
 - Can be quantified arbitrarily using the **API gravity value** of crude oil
 - **API = $141.5/SG - 131.5$** ← ↓
 - **API ↓ Bitumen Yield ↑**
- **Fractional distillation** separates crude oil into streams varying in boiling point.
- Carried out in tall fractionating columns where punctured steel trays allows vapor to rise and condense.



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So, let us now discuss about the production process of bitumen. As I initially told you that bitumen is a crude oil product or a petroleum product and bitumen is obtained as one of the components when this crude oil is subjected to fractional distillation in the distillation tower. As different crudes from at different locations are unique in themselves they can differ significantly from each other and therefore the bitumen yield from different crude sources can also significantly differ from each other.

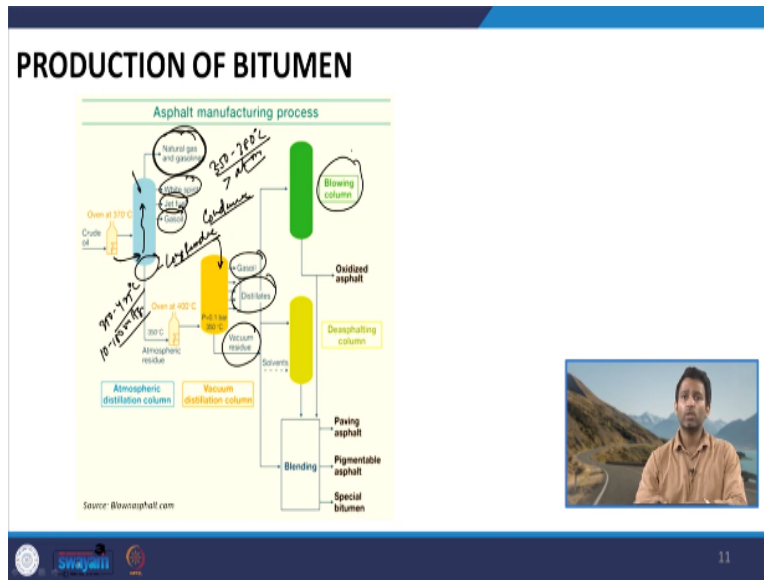
Some crude produce larger quantities of bitumen and these crudes are called as heavy crudes and some crude produce relatively lower quantities of bitumen. So, the bitumen yield of any crude oil can be indirectly determined using an empirical parameter which is called as API gravity value, API stands for American Petroleum Institute and this is mathematically can be written as $\frac{141.5}{SG} - 131.5$.

So, here you can understand that for heavy crude the specific gravity will be more, so if this specific gravity is more, this quantity will be less, so lower is the API gravity higher will be the bitumen yield, this is just an indirect method to determine the yield of the bitumen from the parent crude oil.

Now, let us talk about the process by which the bitumen is produced. So, bitumen is produced through the fractional distillation of crude oil and in the fractional distillation, this crude oil it gets separated into various other components of different boiling points. This process is done in a tall fractionating column,

where we have at different heights, we have punctured steel trays, now when the crude oil is heated in this tray, the vapor will rise, once the vapor rise they will cool and at a particular height when any component present in the crude oil is at a temperature which is close to its boiling range it will condense and at from that tray the that particular fraction can be separated.

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Let us try to understand this using this particular flowchart. In the fractionating column which you see here, the crude oil is introduced at the lower part of the column and it is heated to approximately 350 to 380 degree Celsius and is subjected to a pressure which is little higher than the atmospheric pressure.

Once the crude oil is introduced and in heated form, the vapors will start rising in the column, once it rises in the column it subsequently loses heat, now when each fraction in the crude oil reaches that particular puncher tray where the temperature is just below the boiling point, that particular fraction will condense into liquid and can be collected. The highest fraction which is propane and butane remains at the top of the column and heavier fractions they are obtained as we move down in the column.

So, after propane and butane we will have naphtha which is the feedstock for gasoline, we have kerosene which is basically a aviation fuel and is also used for domestic purposes, then we have gas oil which is the feed stock for diesel engine oil and in the lowest part of the column we will obtain something which is called as the long residue.

Now, this long residue is basically not the material we call as bitumen and use for paving application, this long residue is further subjected to vacuum distillation in a vacuum distillation column. Here the bitumen is heated to a temperature of around 350 to 425 degree Celsius and is subjected to vacuum pressure of

around 10 to 100 mm of hg, if we give higher pressure to this long residue a thermal degradation of the component can take place which is not very desirable.

So, in this particular vacuum distillation column what we obtain, we obtain gas oil, we obtain distillates and finally in the lower part we obtain something which is called as vacuum residue or the short residue and this short residue is actually the feed stock for the production of paving bitumen.

In order to change the properties of the short residue for example, to increase the viscosity of the short residue, the short residue can be further subjected to other processes such as oxidation and which is called as blowing of the bitumen, this is typically done to change the physical properties or the stiffness characteristic of the bitumen and different grades of bitumen can be obtained for different applications.

Well, this brings us to the end of the first presentation and if we recap today we have talked about the origin of bitumen, we briefly discussed about the historical uses and development of bitumen, we discussed about various other binders for example, tar and natural bitumen and then we discussed about the production of asphalt binder, which is done through fractional distillation of crude oil and we saw how in the refinery the crude oil is subjected to different processes to finally obtain the bitumen which is used for paving application.

Thank you everyone and in the next class, we will start discussing about the chemistry of bitumen, thank you.