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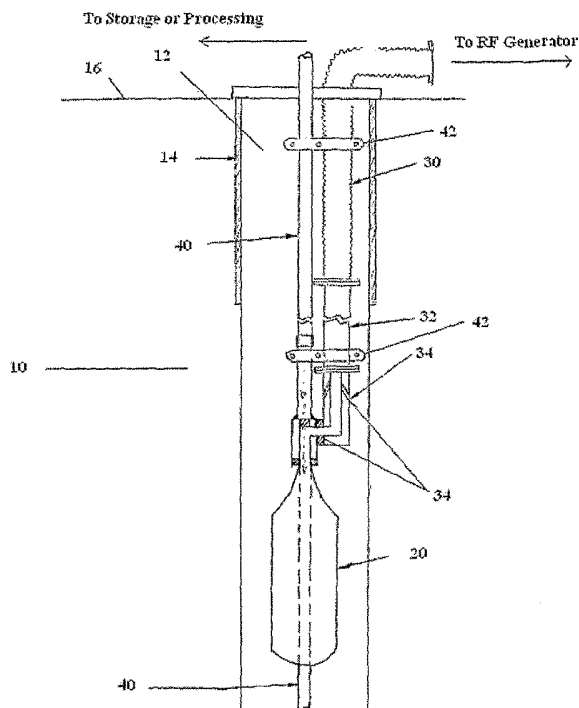
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(54) Title: DOWN HOLE PHYSICAL UPGRADING OF HEAVY CRUDE OILS BY SELECTIVE ENERGY ABSORPTION



(57) Abstract: The present invention utilizes the ability of electromagnetic energy at the appropriate frequency to selectively deposit thermal energy in the heavy oil for precise control of cracking temperature throughout a given volume of material. Selective electromagnetic energy absorption in the heavy crude oil provides energy efficient transfer of heat at the molecular level and thereby insures precise temperature control throughout the treatment volume. This allows for optimization of the visbreaking process using electromagnetic energy.

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DOWN HOLE PHYSICAL UPGRADING OF HEAVY CRUDE OILS BY SELECTIVE ENERGY ABSORPTION

FIELD OF THE INVENTION

[001] The present invention relates generally to the use of electromagnetic energy to subject heavy crude oil to mild thermal cracking conditions, thereby lowering the viscosity, pour point, and specific gravity of the oil and rendering it easier to recover and handle. More particularly, this invention relates to methods for applying electromagnetic energy to heavy oils in the reservoir to promote *in situ* upgrading and facilitate recovery. This invention also relates to systems to apply electromagnetic energy to heavy oils *in situ*.

BACKGROUND OF THE INVENTION

[002] Heavy crude oil presents problems in oil recovery and production. Crude oils of low API gravity and crude oils having a high pour point present production problems both in and out of the reservoir. Extracting and refining such oils is difficult and expensive. In particular, it is difficult to pump heavy crude oil or move it via pipelines.

[003] Various methods to ameliorate the disadvantages of heavy crude oil are used today. For example, the oil industry reduces surface handling problems by blending heavy crude oil with light oils and liquid propane gas to make them easily handled in pipelines and storage facilities. This method has drawbacks, however, as it does not assist in the initial recovery of the oil, and it is expensive.

[004] A process called "visbreaking," or mild thermal cracking, may also be used to reduce the viscosity of heavy crude oil. "Visbreaking" is an oil refinery process for increasing the pumpability of heavy crudes. It typically is accomplished by heating heavy crude oil in a furnace. The process is characterized by mild decomposition, minimum coke formation and the retention of the cracked product in the original feed stock. The resultant mixture has viscosity, pour point, and specific gravity values that are lower

than the original oil. However, as applied today, visbreaking cannot be used on oil *in situ*.

[005] The present invention applies visbreaking new contexts and for new purposes, and proposes improved methods for the application of visbreaking. In the present invention, visbreaking is accomplished using electromagnetic energy to heat the heavy crude oil, rather than heating it in a furnace. Furthermore, the present invention is suitable for use in the treatment of oil *in situ*. Such treatment permits the upgrade of the oil in reservoir and assists in the recovery of the oil.

BRIEF SUMMARY OF THE INVENTION

[006] The present invention utilizes the ability of electromagnetic energy at the appropriate frequency to selectively deposit thermal energy in the heavy oil for precise control of cracking temperature throughout a given volume of material. Selective electromagnetic energy absorption in the heavy crude oil provides energy efficient transfer of heat at the molecular level and thereby insures precise temperature control throughout the treatment volume. This allows for optimization of the visbreaking process using electromagnetic energy.

[007] Proper selection of frequency and power duration results in the rapid cracking of heavy hydrocarbons to any degree desired by electromagnetic energy absorption. When the desired degree of cracking is reached, the hot oil matrix provides a significantly different set of electrical properties which can be measured on the surface during the “**electromagnetic visbreaking process.**” (EVP) to insure precise down hole temperature and power control.

[008] This proposed EVP provides efficient energy absorption and control of thermal cracking of heavy oils for *in-situ* upgrading. The application of low power (a few ten's of kilowatts) electromagnetic energy to the formation for visbreaking will provide mild decomposition of the heavy oil, minimum coke formation and the retention of the cracked product in the

original feedstock. The resultant mixture has viscosity, pour point, and specific gravity values which are lower than those of the original oil.

[009] The present invention several promising applications. It can be used to upgrade heavy crude oil *in situ*. It can also assist in the recovery of heavy crude oil from reservoirs. Further, the present invention can be used to more efficiently recovery hydrocarbons from oil shale, such as that present in the Western United States.

[010] In one embodiment of the invention, a system may be provided for use in treating heavy crude oil underground. The system may comprise a borehole in an area in which crude oil exists in the ground, an electromagnetic energy applicator positioned within the borehole in the vicinity of the heavy crude oil to be treated, a cable attached to the electromagnetic energy applicator to supply electromagnetic energy to the applicator, an electromagnetic energy generator attached to the cable to generate electromagnetic energy to be supplied to the applicator, and a product return pipe running through the borehole, the product return pipe comprised of a distal end positioned in the vicinity of the electromagnetic energy applicator through which oil or other products may be recovered and a proximal end on or near the surface of the ground.

[011] In another embodiment of the invention, a method for treating heavy crude oil underground is provided. The method comprises the steps of positioning an electromagnetic energy applicator in a borehole in the vicinity of heavy crude oil, generating electromagnetic energy, applying the electromagnetic energy to the heavy crude oil with the applicator to achieve thermal cracking, and recovering heavy crude oil through a product return pipe.

[012] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings

and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[013] Fig. 1 is a perspective view of a single borehole radiation type applicator.

[014] Fig. 2 is a close up view of a portion of the applicator system.

[015] Fig. 3 is a perspective view of a portion of another configuration of a single borehole applicator.

[016] Fig. 4 is a perspective view of a wellhead for use with the applicator system.

[017] Fig. 5 shows a sample of the absorption data from experiments on the application of electromagnetic energy to large oil molecules in oil shale.

DETAILED DESCRIPTION

[018] A variety of different types of down hole electromagnetic structures may be employed to apply electromagnetic energy to heavy crude oil *in situ*. The proper structure for any particular application depends on a variety of factors, including depth, heat uniformity, and minimizing the degree of coking and production of unsaturated hydrocarbons.

[019] Fig. 1 is a perspective view of a single borehole radiation type applicator. Applicator system 10 is positioned within borehole 12. Borehole 12 is supported by casing 14. Applicator system 10 is then used to apply electromagnetic energy to heavy crude oil in the vicinity of borehole 12.

[020] Applicator structure 20 is a transmission line retort. For a point of reference, a typical applicator 20 may be approximately 70 feet long. In a typical configuration, the applicator 20 may be positioned from between 100 to 600 feet underground in borehole 12. Radiofrequency ("RF") energy is supplied to applicator 20 by an RF generator (not shown). The RF generator is connected to applicator 20 via a portion of flexible coaxial cable 30. In turn, the flexible coaxial cable 30 is connected to a portion of rigid coaxial

cable 32. The coaxial cable may or may not be supported by ceramic beads, which are desirable at higher temperatures. By this means, the RF generator supplies RF energy to applicator 20, which in turn applies RF energy to the target volume to achieve visbreaking. This allows *in situ* upgrading of the heavy crude oil and assists in recovery.

[021] Recovery of the oil and related products is achieved by means of production pipe 40. This non-metallic pipe runs from the production area of borehole 12 through the borehole to surface 16. At the surface, production pipe 40 is connected via a product return line to a storage or processing facility (no shown).

[022] Production pipe 40 provides a firm mounting base for the RF hardware of applicator system 10. Coaxial cables 30 and 32 can be attached directly to production pipe 40 using connectors 42. Applicator 20 also attaches to production pipe 40.

[023] Fig. 2 is a close up view of a portion of the applicator system. Applicator structure 20, rigid coaxial cable 32, and production pipe 40 are all positioned within borehole 12. Typical dimensions for such a system are shown in Fig. 2. Ceramic support beads 34 support rigid coaxial cable 32. Further, ceramic pressure window 36 is placed at the tope of applicator 20.

[024] Fig. 3 is a perspective view of a portion of another configuration of a single borehole applicator. In this configuration, a dipole feed is used. Coaxial feed 38 surrounds production pipe 40. Ceramic window 36 is placed at the bottom of coaxial feed 38.

[025] Although specific examples of applicator structures are given, it is understood that other arrangements known in the art could be used as well. Uniform heating may be achieved using antenna array techniques, such as those disclosed in U.S. Patent No. 5,065,819. Such techniques can be used to minimize coking conditions at the applicator borehole and avoid excessive electrode voltage gradients at high power. Arrays reduce excessive voltage gradients at the borehole by means of mutual coupling. The ability to separately measure reflected power from each applicator borehole containing

radiator and mutual impedance coupling between any pair of applicator boreholes insures precise temperature control of the heated volume.

[026] Other variations are possible, including non-radiation structures such as those proposed in J. Bridges, et al., "RF Heating of Utah Tar Sands," Final Report, IIT Research Institute. However, such structures are sensitive to high voltage breakdown and require extensive drilling which is not economical.

[027] A special wellhead may be used in conjunction with applicator system 10. Properly designed, the wellhead can be used to provide safe and efficient delivery of RF energy to the applicator.

[028] Fig. 4 is a perspective view of a wellhead for use with the applicator system. The weight of the down hole applicator (not shown) rests on a special bellows 46 within the wellhead. This insures that any heat induced mechanical movements of the down hole apparatus during energy transfer do not interrupt power flow. An input opening 44 permits nitrogen to be introduced into the interior of the wellhead and borehole, further ensuring the safe application of RF energy. Insulators 45 are positioned above the bellows 46, and a center conductor expansion joint is positioned on top of that. At the top of the wellhead, where coaxial cable 30 exits and runs to RF generator 28, a coaxial line seal and vertical alignment clamp 26 secure the cable to the wellhead. Product return line 41 carries the product recovered through the system to a storage or processing facility (not shown), and water extraction line 43 permits the removal of water from borehole 12.

[029] The present invention also has application in oil shale fields, such as those present in the Western United States. Large oil molecules that exist in such oil shale have been heated in a series of experiments to evaluate the dielectric frequency response with temperature. The response at low temperatures is always dictated by the connate water until this water is removed as a vapor. Following the water vapor state, the minerals control the degree of energy absorption until temperatures of about 300-350 degrees centigrade are reached. In this temperature range, the electromagnetic energy begins to be preferentially absorbed by the heavy oil. The onset of this

selective absorption is rapid and requires power control to insure that excessive temperatures with attendant coking do not occur. Fig. 5 shows a sample of the absorption data from such experiments.

[030] Because of the high temperature selective energy absorption capability of heavy oil, it is therefore possible to very carefully control the bulk temperature of down hole crude oil heated by electromagnetic energy. The energy requirement is minimized once the connate water is removed by steaming. It takes much less energy to reach mild cracking temperatures with electromagnetic energy than any other thermal means to provide visbreaking.

[031] Kasevich has published a molecular theory that relates to the specific heating of heavy oil molecules. He found that by comparing cable insulating oils with kerogen (oil) from oil shale, a statistical distribution of relaxation times in the kerogen dielectric gave the best theoretical description of how electromagnetic energy is absorbed in oil through dielectric properties. With higher temperatures and lowering of potential energy barriers within the molecular complex a rapid rise in selective energy absorption occurs.

[032] In use, a user of an embodiment of the present invention would position an applicator system in a borehole in an area in which heavy crude oil exists. The user would position the applicator structure itself in the borehole in the target area for application of RF energy. The user would connect the applicator structure to an RF generator via coaxial cable. A production pipe would run from the area of production to the surface, and from there to a storage or processing facility. The user would then apply RF energy using the RF generator to the applicator, thereby applying the RF energy to the heavy crude oil *in situ*. The RF energy would be controlled to minimize coking and achieve the desired cracking and upgrading of the heavy crude oil. The resulting products would then be recovered via the production pipe and transferred to a storage or processing facility.

[033] Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A system for use in treating heavy crude oil underground, the system comprising:
 - a borehole in an area in which crude oil exists in the ground;
 - an electromagnetic energy applicator positioned within the borehole in the vicinity of the heavy crude oil to be treated;
 - a cable attached to the electromagnetic energy applicator to supply electromagnetic energy to the applicator;
 - an electromagnetic energy generator attached to the cable to generate electromagnetic energy to be supplied to the applicator; and
 - a product return pipe running through the borehole, the product return pipe comprised of:
 - a distal end positioned in the vicinity of the electromagnetic energy applicator through which oil or other products may be recovered; and
 - a proximal end on or near the surface of the ground.
2. The system of claim 1 wherein the applicator is an antenna array.
3. The system of claim 1 wherein the applicator is a solenoid antenna.
4. The system of claim 1 wherein the applicator is a helical antenna.
5. The system of claim 1 in which at least one of the cable and applicator are attached to the product return pipe.

6. The system of claim 1 in which the product return pipe is connected to a storage or processing facility.
7. The system of claim 1 further comprising:
a wellhead at the surface of the borehole, the wellhead comprising:
a bellows connected to the applicator structure in such a way that the bellows supports the weight of the applicator.
8. The system of claim 7 further comprising a sealable opening for the introduction of gas to the wellhead and borehole.
9. A method for treating heavy crude oil underground, the method comprising the steps of:
positioning an electromagnetic energy applicator in a borehole in the vicinity of heavy crude oil;
generating electromagnetic energy;
applying the electromagnetic energy to the heavy crude oil with the applicator to achieve thermal cracking; and
recovering heavy crude oil through a product return pipe.
10. The method of claim 9, further comprising the steps of:
controlling the electromagnetic energy applied to the heavy crude oil in order to upgrade the heavy crude oil *in situ*.
11. The method of claim 9, in which the electromagnetic energy is applied to heavy crude oil in oil shale.

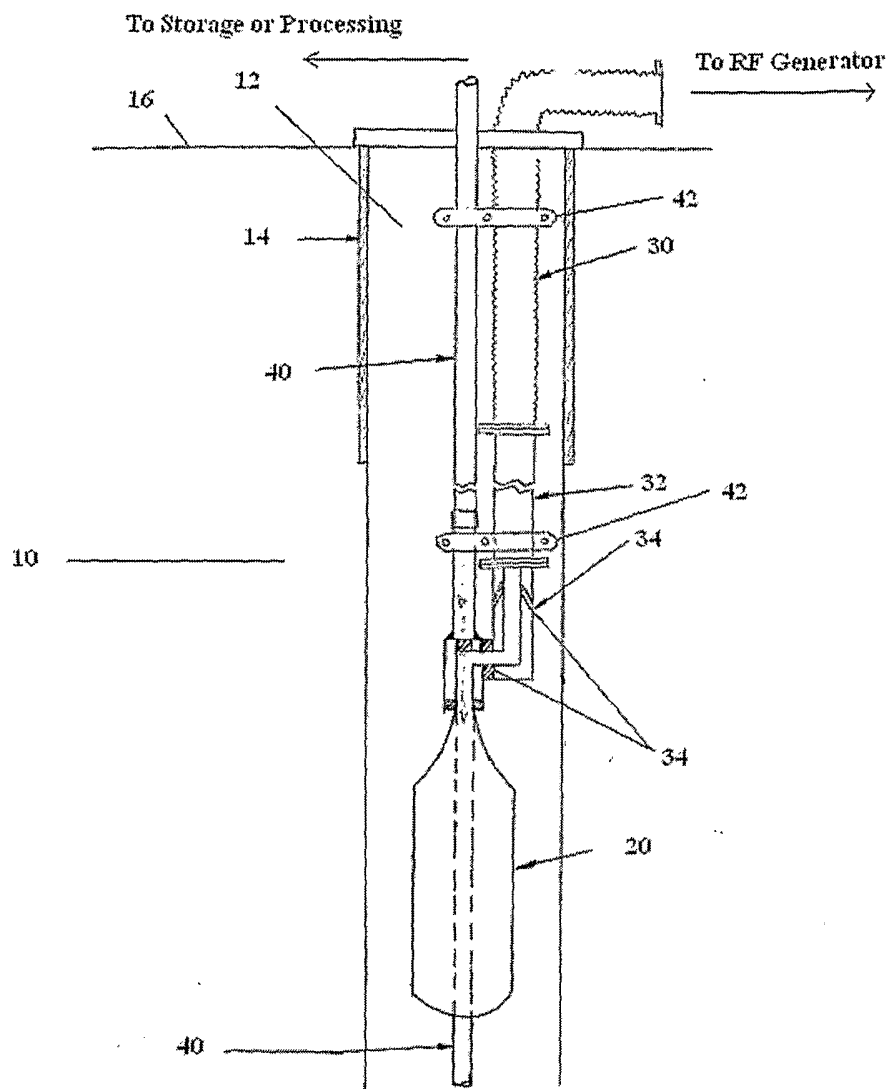
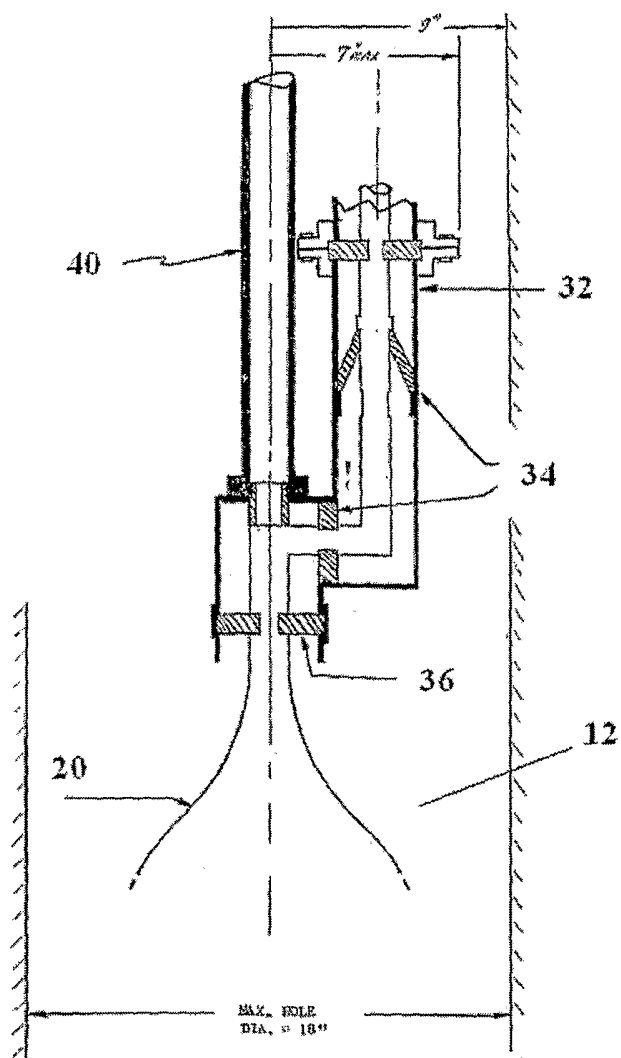


Fig. 1



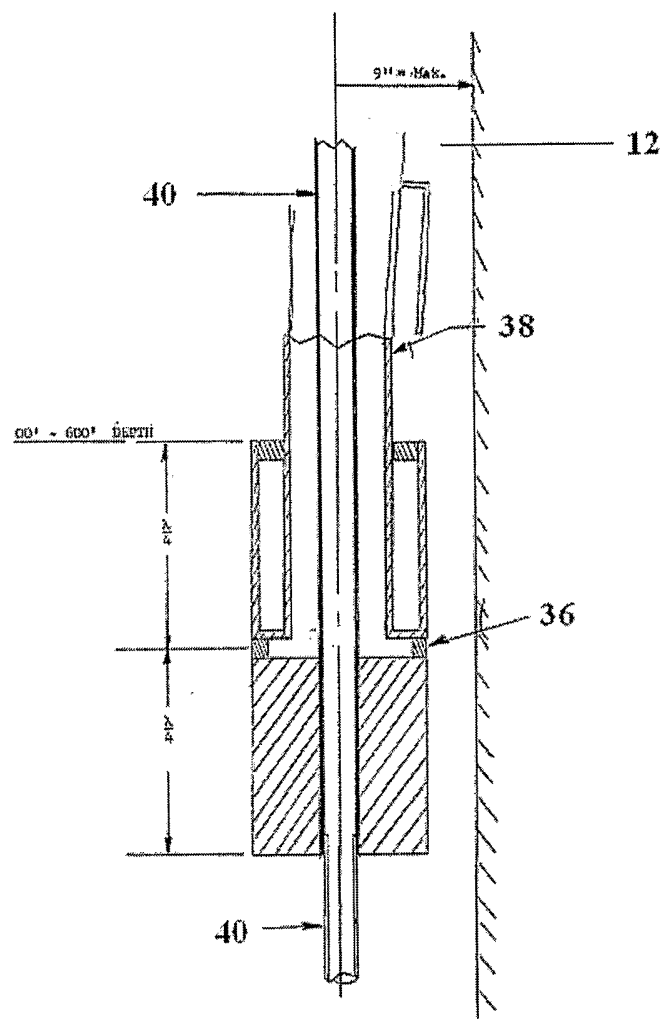


Fig. 3

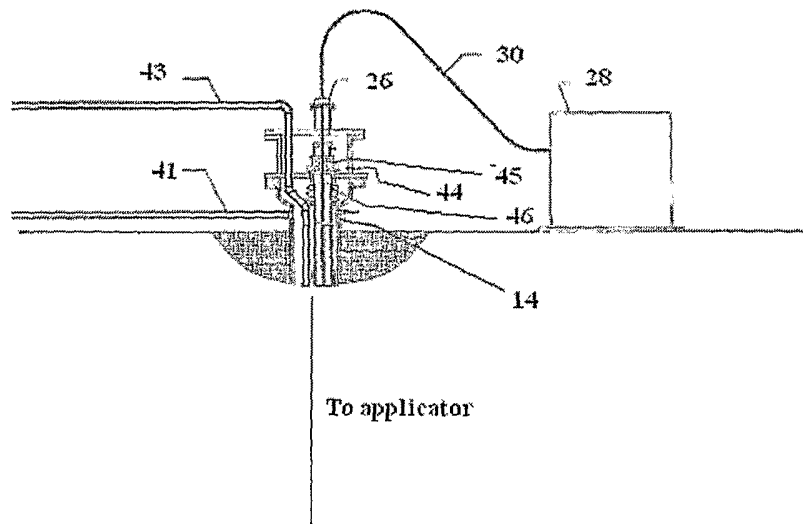


Fig. 4

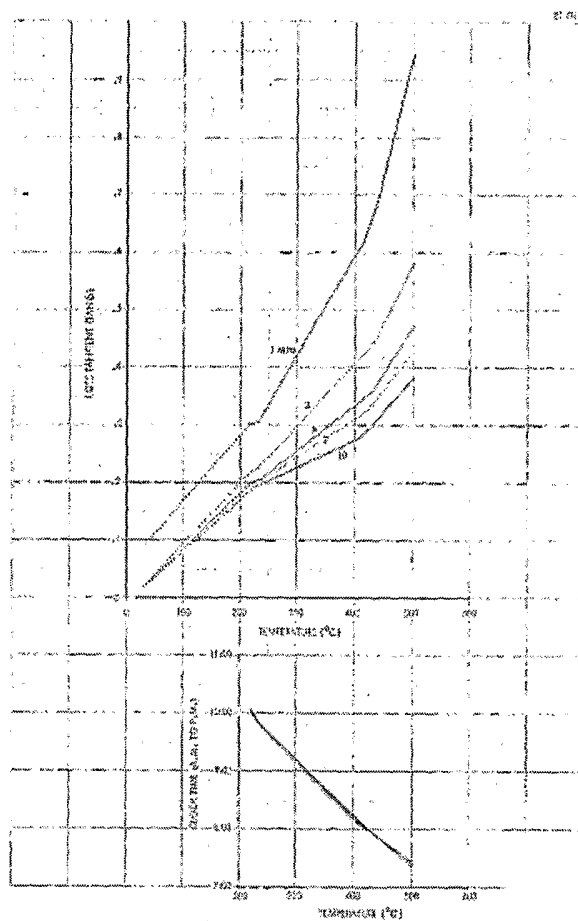


Fig. 5