THE RECOVERY OF GASOLINE FROM THE
DISCHARGE GAS OF COMPRESSION
PLANTS

A THESIS SUBMITTED TO THE FACULTY OF
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Recovery of Gasoline from Residue Gas from Natural Gas Compression Plants.

Introduction.

The great war has particularly impressed us with the paramount importance and value of petroleum and its products and more especially gasoline. With the ever increasing number of motor driven vehicles coming upon the market it behooves us to use all conceivable methods which will conserve the supply of gasoline, if we are to have an adequate supply.

This paper deals with the conservation of gasoline at compression gasoline plants where motor fuel is extracted from casinghead gas by means of mechanical compression and cooling. The method presented is the application of the absorption* process to the residual gas from compression plants. In the absorption system the gasoline vapors in the natural gas is absorbed by heavy oil and subsequently separated from it by steam distillation as in refinery practice.

"Manufacturing Gasoline by the Absorption Process", Mining & Oil Bulletin October, 1918.
Objections to Installing Absorption Process in Conjunction with Compression Plants.

The efforts of casinghead gasoline engineers to devise means of substituting the absorption method for the compression process in plants using gas of average gasoline content have demonstrated the practicability of the absorption process, as some of the most efficient gasoline plants in the Mid-Continent field are absorption plants. Such men are deserving of much credit as the manufacturers were very much skeptical of its success. Now we are confronted with the same proposition, namely of overcoming the prejudice of operators in installing absorption towers to treat the residue gas from compression plants. The chief objections against equipping a plant for the extraction of gasoline from waste gas is that the gasoline recovered is too "wild" to hold, and that the quantity obtained in most cases is too small to warrant the installation, and remunerate the producers in costs of operation.

Cost of Absorption.

Assume a concrete case of gas containing .40 of a gallon per thousand cubic feet of gas, 500,000 cubic feet of residue gas
at 200 pounds working pressure.

If the absorption medium used is naphtha, the only extra construction needed is one absorption tower and auxiliaries such as pumps etc., with no additional labor costs in operation. The gross income on such an installation would be $1320 per month (absorption gasoline @ .224 per gallon) if we totally disregard the increase in volume and gravity of the naphtha due to some of the higher gases which will be permanently held in solution.

Of the initial cost,
On the same assumptions, a plant using mineral seal oil as the absorbent and subsequently distilling to separate the gasoline, should not exceed $6,000 and the operation costs increased by the wages of one extra man on each tour plus upkeep costs.

Quality of Product Obtained.

If we assume that a compression plant is working at a pressure of 214# per square inch and that the gas is cooled to 90°F. the residue gas will contain .5 gallons per thousand cubic feet of hexane which has a gravity of 78.9°Be, at 70°F the discharge gas will
EXTRACTION OF HEXANE BY COMPRESSION

Assumption One Half Gallon Hexane per 1000 Cu. Ft. at 90° F. Pressure 214 lbs.

Temperature (Degrees F.)

Gallons per 1000 Cu. Ft. of Gas.

U. S. Bureau of Mines
Nov. 1, 1918.
contain .39 gallons per thousand cubic feet, as is shown by the curve in Fig. 1, at 90°F and 214# pressure the residue gas would contain .17 gallons of heptane (gravity 70.9°Be.) per thousand cubic feet and at 70°F would contain .11 gallon per thousand cubic feet of gas.

These data show that regardless of what the working pressure or temperature may be in the compression operation, the gas which has been treated by compression will contain some low gravity hydrocarbons and that operators are laboring under a false apprehension when they entertain the idea that the gasoline in the residue gas is so wild that even if it was possible to recover it, that it would rapidly weather away.

The Efficiency of Compression System.

In the operation of compression gasoline plants there are three prime factors which control the efficiency of extraction namely: pressures, temperature to which compressed gas is cooled and dilution of gas by means of air or dry gas.

Pressures.

Plant operators have been repeatedly urged to make a series
of experimental runs to determine the most suitable working pressure. The criterion as to pressure used at new plants is that used by other plants in the same field or in some other district with which the operators may be familiar. As the field get older, the gasoline content of the gas increase and consequently can be extracted at lower pressures and still produce the maximum quantity of salable product consequently this feature must be taken into consideration if plants are to be operated efficiently.

Temperature

Temperature conditions are just as important as pressures since they are absolutely interchangeable. A mistake made by many operators is using too much water and flooding the coils. In using large quantities of water, the large cooling result by evaporation is not effected and one only obtains a heat interchange similar to hot and cool oil heat exchanger. One should have only a thin film of water on the coils in order to get the maximum cooling.

The cooling effect resulting from one pound of water cooling from 80°F to 79°F will be 1 B.T.U. provided there is no evaporation, whereas if this quantity of water is permitted to evaporate it
will absorb 992 B.T.U. of heat, from which it is quite apparent that too much water is more inefficient than too small a quantity.

Submerged coils are not recommended in casinghead gasoline practice. With aerial coils oft times it is possible to obtain temperatures as low as 65°F in the Mid-Continent field in summer depending upon the relative humidity but with submerged coils the lowest temperatures which one could ever expect to procure would be the original temperature of incoming water.

A large number of compression plants have been visited which have absolutely no record of temperatures, in fact, at some plants the only thermometer on hand was that on the stem of the hydrometer. Thermometer wells should conveniently located around plant.
Dilution of Gas.

At a majority of the plants in the Mid-Continent field practically no attention is paid to the dilution of the casinghead gas by dry gas and more especially by air. The gas is contaminated with air through leaks in the vacuum lines, defective casingheads, improperly packed stuffing boxes and leaky stop cocks. One can readily ascertain the air content by a small portable gas analysis apparatus* which are on the market but simply because chemicals and some glass bulbs are employed, the operators consistently pass it up as a mystery.

Dry gas is just as detrimental as air as a dilution agent of gas to be treated. One case has come to the writer's attention where a gas containing one gallon of gasoline per thousand cubic feet was being drawn in to the same line as gas having a gasoline content of seven gallons per thousand cubic feet, upon discarding the entire supply of the dry gas, the production was increased, lower pressures employed and the quality of the product recovered.

materially improved. Some plants have two sets of coils and compressors where two gases of altogether different richness are treated and the gas supplies will warrant which is excellence practice. Specific gravity (air free basis) of gases will usually indicate a dry gas and in case the result is doubtful, the richness of gas in question can be confirmed by a compression or absorption test.

Limitations of Compression Process.

It is impossible to extract all of the gasoline in casinghead gas by means of compression unless prohibitive pressures are maintained even with rich gases the efficiency of recovery necessarily decreases as the gas get leaner and their resulting partial vapor pressures increases. It has been stated that the compression system will extract all of the gasoline from wet casinghead gas, certainly from gases containing two gallons or more per 1000 cubic feet.

The writers have tested the residue gas from plants operating at 72°F (gas in accumulators) on 10 gallon gas which were losing as
much as 340 gallons per million cubic feet of gas which would un-
 doubtedly be economically to recover by absorption.

Partial Vapor Pressures.

The underlying principles governing all processes used for 
extracting gasoline from natural gas takes in consideration partial 
vapor pressures of the gasoline hydrocarbons and one can have a 
clear understanding of the various procedures only by dealing direct-
ly with the partial vapor pressure generalization.

All gases diffuse into one another and the process goes 
on until each gas is uniformly distributed throughout the entire 
space. If the pressure of each gas be measured separately, it will 
be found that the diffusion continues until the pressure of any 
given gas is the same in all parts of the space, and it will be 
found that the pressure exerted by each gas is the same as that 
which the given mass of the gas would have exerted if it alone were 
occupying the entire space. This pressure is called its partial 
vapor pressure. The total pressure of a gaseous mixture is the 
sum of all the partial pressures of its component gases. The volume 
of each gas is the total volume of the space occupied by the entire
gaseous mixture. The law* which describes these phenomena is known

*Dr. H. P. Cady -- Inorganic Chemistry.

As Dalton's Law of Partial Pressures, and may be stated as follows:

Each gas in a gaseous mixture, fills the entire space occupied by the gaseous mixture and the total pressure of the mixture is the same as the sum of the partial pressures of the component gases.

Let $V$ represent the total volume of the component gases and $V_a$, $V_b$, $V_c$, the volume of the separate gases and the total pressure by $P$, and the partial pressures by $P_a$, $P_b$, and $P_c$. Then

$$V_a = V_b = V_c = V$$

$$P_a + P_b + P_c = P$$

Table #1:

Vapor Pressures and Corresponding Temperatures at Which Certain Hydrocarbons will condense.*

<table>
<thead>
<tr>
<th>Temperature F.</th>
<th>Vapor Pressure lbs. per sq. inch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases</td>
<td>Vaccine : Butane : Petane : Hexane : Heptane</td>
</tr>
<tr>
<td>$C_2H_8$</td>
<td>$C_4H_{10}$ : $C_5H_{12}$ : $C_6H_{14}$ : $C_7H_{16}$</td>
</tr>
<tr>
<td>32</td>
<td>72.5</td>
</tr>
<tr>
<td>40</td>
<td>84.6</td>
</tr>
<tr>
<td>50</td>
<td>100.7</td>
</tr>
<tr>
<td>60</td>
<td>115.4</td>
</tr>
<tr>
<td>70</td>
<td>130.1</td>
</tr>
<tr>
<td>80</td>
<td>147.2</td>
</tr>
<tr>
<td>90</td>
<td>165.0</td>
</tr>
</tbody>
</table>

PARTIAL VAPOR PRESSURE OF HEXANE
ONE HALF GALLON PER 1000 CU. FT.
AT DIFFERENT TEMPERATURES.

Assumption 1 Gallon of Hexane
Occupies 30 Cu. Ft.
For example let us assume a gas to contain 1.5% by volume of hexane (which is approximately .5 gallons per thousand cubic feet) at 80°F, its vapor pressure at 80°F is 2.9 lbs. per square inch as is shown in Table #1

(Table #1 here)

The pressure necessary before the hexane will start to be precipitated is 100 x 2.9 or 193 pounds per square inch. The pressures necessary to cause the hexane to start to condense at other temperatures is shown by curve in Fig. 2. Let us assume the gas in the above illustration is contaminated with 50 percent dry gas or air; the hexane content will be decreased to 0.75% and a pressure of 386# per square inch will be necessary in order that the hexane will start to precipitate. The same reasoning applies to pentane, heptane etc. in cahing-head gas and on the partial vapor pressure of each component depends the pressure at which the compressor must be worked in order to extract the gasoline.

In the absorption system, partial pressures of the various recoverable constituents is equally important as the wide generalization which governs the absorption procedure may be stated as follows:

Each particular hydrocarbon will continue to be dissolved in the
in the absorption medium until its partial vapor pressure in the
gas is equal to its partial vapor pressure from the absorption
menstrum. For example hexane in a mixture of gases, will dissolve
in mineral seal oil until its partial vapor pressure in the gas
is at equilibrium with its partial vapor pressure from the oil.
Each individual hydrocarbon absolutely independent of each other
consequently one cannot say that 4\% or any other figure is the
best saturation to operate an absorption plant at until some ex-
perimental work has been done, as the characteristics of the hydro-
carbon in the gas will determine the most efficient saturation to
use. It is obvious that a gas containing say 0.5\% pentane, 0.5\%
hexane and 0.5\% heptane can be treated by the absorption process by
using less oil (other factors being equal) than a gas containing
1.5\% pentane since the solubility of each component is independent
of another gas. With dry gases in the Mid-Continent field having
0.20 of a gallon of gasoline per thousand cubic feet of gas and
circulating 5 or 6 gallons of mineral seal oil per thousand cubic
feet of gas, the discharge gas will contain between 0.02 and 0.03 gallons
per thousand cubic feet of gas. This is the point of equilibrium
between the partial vapor pressures of hydrocarbons in the gas and the partial vapor pressures of the hydrocarbons dissolved in the mineral seal oil.

Field Data.

The residue gas from compression plants located in the representative fields of the Mid-Continent district was tested by the absorption apparatus described in part II of this paper. The data accumulated is shown in Table II.

Discussion of Data.

The first plant tested is indicated by #1 in the Bartlesville field. The results of the investigation showed that the plant was losing .480 gallons per thousand cubic feet of gas. Efforts to increase the plant production by mechanical adjustments, such as changing pressures and temperatures of cooling, and examining the raw gas for air or dry gas dilution were in vain. Recommendations were made to the company for the erection of absorption towers to treat the residue gas using naphtha as the absorption agent if possible. A preliminary test by the portable absorption apparatus using naphtha gave the following results: (Data here - Test 10P)
Test 10 P.

Residue Gas

Temperature of naphtha (beginning) 72°F.
Temperature of naphtha (finish) 82°F.

Average 77°F.

Pressure 265#

Rate of flow 141 cu. ft. per hr.
(1 hr. 25 min.) 2.35 cu. ft. per minute
Volume 200 cubic feet

1st. Compartment 2nd. 3rd.
Charge 2600cc 2600 cc 2600 cc
Recovered 3100 2940 2720
Increase in volume 15.4% 13.1 4.6
L.P.P. 114 119 129
Gravity 56.1 54.6 51.7
Vapor pressure @ 100°F.* 3.5# 2.7 2.0
Gravity° 54.8 53.3 51.5

* Temperature of charge was 82°F., so could not get V.P. at 70°F.
° After V.P. had been taken.
The volume of naphtha was increased by 15.4% in the first compartment and gravity raised from 51.1°Be to 56.1 where as the vapor pressure at 100°F was only 3.5 pounds per square inch. The distillation curves of products recovered in each compartment is given in Fig. III. Attention is called to the coincidence of curves above 60 per cent as not being absolutely true as they deviate slightly from concurrence.

The absorption system installed consisted of three 20-ft. joints of 20-inch standard casing connected in series. Each tower was filled with about eight feet of naphtha. The gas bubbles through the naphtha until the gravity of product in the first absorber reaches 63° Be., when the gravity of stock in second and third towers attained gravities of 58° Be. and 57° Be. respectively when using 52°Be. naphtha. The time required is usually eight hours. The blended product from the three towers has a gravity of approximately 59°Be. and a vapor pressure of 7 pounds per square inch. The extremes of data on plant production from these towers so far are:

<table>
<thead>
<tr>
<th>Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic feet gas treated</td>
<td>511 M</td>
</tr>
<tr>
<td>Gallons of blended product obtained</td>
<td>1213</td>
</tr>
<tr>
<td>Gallons of naphtha used</td>
<td>731</td>
</tr>
<tr>
<td>Gallons gain</td>
<td>422</td>
</tr>
</tbody>
</table>
Table # 3.

<table>
<thead>
<tr>
<th>Time</th>
<th>Naphtha(1)</th>
<th>Compression Blend(2)</th>
<th>Absorption Blend(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gravity</td>
<td>Loss</td>
<td>Gravity</td>
</tr>
<tr>
<td>00</td>
<td>50.8</td>
<td>0%</td>
<td>63.4°Be</td>
</tr>
<tr>
<td>2 hrs</td>
<td>50.8</td>
<td>0</td>
<td>63.0</td>
</tr>
<tr>
<td>4 hrs</td>
<td>50.7</td>
<td>5</td>
<td>62.6</td>
</tr>
<tr>
<td>6 hrs</td>
<td>50.6</td>
<td>7</td>
<td>62.4</td>
</tr>
<tr>
<td>24 hrs</td>
<td>50.6</td>
<td>1.2</td>
<td>60.4</td>
</tr>
<tr>
<td>48 hrs</td>
<td>50.5</td>
<td>2.0</td>
<td>59.4</td>
</tr>
</tbody>
</table>

Temperatures during weathering varied from 51°F. to 72°F. 500 cc. graduated cylinders were filled and the data recorded is significantly comparative.

(1) Naphtha used in making blends.

(2) Product made by blending naphtha and condensate from high and low accumulators.

(3) Stock made by absorption towers through which the residue gas passed.
DISTILLATION CURVE
RESIDUE GAS ABSORBER.
500 M cubic feet of gas treated
963 Gallons of blended stock produced
700 Gallons of Naphtha used
263 Gallons increase.

The distillation curves of naphtha charged into absorption towers and the absorption product obtained is shown in Fig. IV. The weathering losses of the various products at this plant is given in Table III.

The residue gas now averages .10 gallons of gasoline per thousand cubic feet of gas, whereas the pressure on the discharge of high stage compressor is 250 pounds per square inch as before installing the absorption process on the residue gas and the production of low and high stage compressor condensate has not been changed.

The cost of installation of the absorption equipment was about $800.00 and no extra expense is incurred in the operation excepting the small costs of up-keep. The profit resulting with the present price of gasoline varies from $84.40 to $52.60 per day simply figuring upon increase in production and not taking into consideration the increase in value of the naphtha by raising its gravity to 58-59 which is sold in the vicinity to garages and makes a splendid motor
Attention is called to Plant #2, Bartlesville field, where two stage expansion engine and double pipe coils are installed. The gas is expanded from 275 pounds per square inch to five pounds per square inch and the high pressure gas is cooled to 35°F. During July and August of 1918 the average production made by this arrangement was 923 gallons and still the residue gas contained .200 gallons per thousand cubic feet of gas.

Plant #5, (Bartlesville field) ran a part of their residue gas through an 18-inch x 20-ft. tower which was filled with crushed rock. Naphtha was used an an absorption menstrum and passed continuously through the absorber, the gravity was increased from 52°Be to 59°Be. The gasoline content of the residue gas with absorption tower in operation was lowered from .336 to .140 gallons per thousand cubic feet of gas.

The compression gasoline at this plant is blended to 67°Be. During one week 2.68 gallons of raw product was required to one gallon of naphtha to obtain this product without the absorption
Illustration #2.
Absorber Operating on Rich Gas.

Illustration #1.
Absorption Tower Treating Residue Gas.
tower in operation the average temperature being 80°F. On the following week the absorption tower was used and only 2.26 gallons of raw condensate to one gallon of naphtha was necessary in order to procure the same gravity with an average temperature of 79°F.

Weathering losses on the product made in the blending tower and that made by blending naphtha and compressor condensate is shown in Table IV.

Attention is called to the low gravity of the absorption stock which is saturated with the permanent gases that increase the gravity and weather more rapidly than the liquid fractions which would have been absorbed to a larger degree provided less naphtha had been circulated and more efficient baffling material installed. Distillation curves on this product is shown in Fig. V.

The blending tower used at this plant is shown in Illus. #1. It is too small to handle all the gas compressed at this plant and is filled with crushed rock as a baffling material which is quite inefficient. Illustration #2 is another set of vertical absorption towers
Table 4.
Weathering Losses of Absorption Blended Stock and That Blended with Compressor Condensate.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>High Product</th>
<th>Blended Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-17-'18</td>
<td>4:40 P.M.</td>
<td>550 cc 57.7°Be</td>
<td>550 cc 57.5°Be</td>
</tr>
<tr>
<td>7-16</td>
<td>9:30 A.M.</td>
<td>500 55.9</td>
<td>490 53.9</td>
</tr>
<tr>
<td>7-19</td>
<td>10:00</td>
<td>480 54.1</td>
<td>486 52.1</td>
</tr>
<tr>
<td>7-20</td>
<td>10:00</td>
<td>468 53.8</td>
<td>457 51.8</td>
</tr>
<tr>
<td>7-21</td>
<td>11:00</td>
<td>450 53.3</td>
<td>445 51.2</td>
</tr>
<tr>
<td>7-22</td>
<td>4:30 P.M.</td>
<td>444 52.4</td>
<td>435 51.0</td>
</tr>
<tr>
<td>7-23</td>
<td>5:00</td>
<td>440 52.4</td>
<td>430 50.6</td>
</tr>
<tr>
<td>7-24</td>
<td>4:00</td>
<td>425 52.4</td>
<td>425 50.4</td>
</tr>
<tr>
<td>7-28</td>
<td>6:00</td>
<td>405 51.6</td>
<td>405 50.0</td>
</tr>
<tr>
<td>8-1</td>
<td>4:15</td>
<td>390 51.6</td>
<td>390 49.8</td>
</tr>
</tbody>
</table>
Illustration #3.
Horizontal Absorbers on Residue Gas.

Illustration #4.
Scrubbers working on Rich Gas.
which are handling eight hundred thousand cubic feet of gas per day.

Plant #26 (Cushing field) is equipped with the absorption system to treat the residue gas. The gas passes through nine horizontal absorbers 16-inch x 40-ft., which are connected in series of three. The top scrubbers contain sprays through which oil is introduced. The oil passes down into the next absorbers where gas is first treated by being allowed to bubble through the mineral seal oil. The arrangement is shown in illustrations 3 and 4. The intake gas on the absorbers is .130 gallons per thousand cubic feet which is cleaned to .028 gallons per thousand cubic feet. It is doubtful whether this absorption installation is an economical success inasmuch as the initial cost of the plant was extremely high and the gasoline content of the residue gas is abnormally low due to the efficient cooling system of the compression plant and the characteristics of the gas being treated.

Plant #28 (Cushing field) is equipped with a combination absorption and refrigeration process to recover the gasoline from the residue gas. Naphtha is cooled by ammonia expansion to 35°F
Illustration #6
Storage tanks from which vapors are recompressed.

Illustration #5.
Refrigeration and absorption system Recompressed.
and pumped into vertical absorbing towers 18-inch by 30-foot, through which the residue gas flows. The towers are insulated by cork and boxed as is shown by Illustration V. The residue gas discharging from these towers contains .15 gallons of gasoline per thousand cubic feet of the gas. The pressure maintained on absorbers is 250 pounds.

The writer are indebted to Lloyd F. Boyer for the following information. The residue gas from the top connections of the high pressure accumulators of the regular compression plant, is cooled in vertical towers by direct contact with chilled gasoline. Gasoline is thus condensed directly into that used as the cooling agent and the blended mixture flows out by gravity from the bottom of the tower into a separating tank. Here the condensed water is removed. The high pressure circulating pump takes its suction from the gasoline in this tank and discharges gasoline through the double pipe ammonia expansion coils and then into the sprays in the tower. Thus a certain quantity of gasoline is continually retained in the system and circulated. As gasoline is condensed in the tower, tending to increase the quantity in the system, the excess overflows into the accumulator tank, from
which it is drawn off into storage. Distillate for blending is
pumped into the system continuously at the proper rate to maintain
the desired gravity of the product.

The gas is treated under the usual compression pressure,
approximately 250 pounds per square inch. It passes through the towers
only once, as the towers are connected in parallel. The refrigeration
equipment is of the usual compression type using single-acting two-cylin-
der York compressors and Shipley flooded condenser. The double pipe
coils are of 2-inch and 3-inch pipe, the gasoline flowing through the
inner pipe. The return bends are extra heavy to withstand the high
pressure.

During the summer months, that is April to October inclusive
the additional yield from the refrigeration system measured in the
storage tanks upon the basis of the original gas taken into the compression
plant was 0.46 gallons per thousand. Of this 0.26 gallons per thousand
was shipped in the cars, the difference being lost in weathering and
loading.
When the system was originally started we used calcium chloride brine as the cooling agent. The mixture of brine and condensate was separated by difference in gravity and the brine was continually circulated. However, so much trouble developed in clogging of piping, freezing and discoloration of product that we abandoned that method.

All of the compressor condensate from this plant is blended to 61-63° Be and the storage tanks (illustration #6) are connected to the intake of one compressor and the vapor which is ordinarily lost while weathering, is compressed to 200 pounds, which gives very remunerative results. The average production of this plant per day is:

- 9000 gallons - from Field Gas.
- 1000 gallons - Absorption on Residue
- 2800 gallons - Compressed Vapors, from weathering tanks.

The average losses of the compression gasoline plants in their residue gas is .337 gallons per thousand cubic feet of gas.

The loss at various temperatures and pressure by actual absorption tests approximately agree with theoretical calculations shown in Fig. 1 and Table #1, although this is not recommended as being a criterion by which to arrive at gasoline content of residue gas but simply
forms a preliminary estimate.

Field Date on Absorption Plants.

Data collected on the gasoline content of the residue or discharge gas from absorption plants is recorded in Table V. The results are much lower than those of compression plants as it is possible to discharge much leaner gas from these plants than by the compression and cooling process. True the absorption system requires more careful attention but the various factors affecting the extraction is not a mystery and vigilant attention to absorption plant operation will give tremendous financial compensation.

Expansion Engines.

Some plants use an expansion engine for extracting gasoline in residue gas. The details by which this is accomplished vary somewhat in different plants but all proceed on the fundamental principle of absorbing the (power) (and consequently the heat) stored in the gas by causing it to perform work, its expansion results in much lower temperature than would otherwise be obtained. The high pressure gas after passing through double pipe coils is admitted to the expansion
cylinder of the expander compressor at the pressure maintained on the high accumulators and is exhausted against a back pressure from five to twenty pounds per square inch through the outside of the double pipe coils, where it serves to cool the compressed gas within the inner tubes. The power developed in the expansion engine is used to compress additional gas. Most of the recent installations two stage expanders are used. They are arranged so as to exhaust first from the high pressure expander cylinder through a set of double pipe coils and then after further expansion in the low pressure cylinder through another set of double pipe coils. The range of temperature is much reduced in a two stage expander than in a single stage type and trouble due to initial condensation and freezing of water is considerably less which gives a greater interchange of heat.

The expansion engines are perhaps the most troublesome features of such gasoline plants that use them. Difficulties coming from the high pressure of initial gas, its extremely low exhaust temperatures, the condensation of moisture and gasoline with the resultant freezing which makes internal lubrication of values and cylinder very difficult.
It has been found that by using glycerine in very small quantities as a lubricant and applying directly to the rubbing surfaces, that the machine can be operated almost continuously.

All these difficulties can be overcome by using a rotary expansion engine* or spiral turbine. The gas passes around the spaces between teeth and causes the gears to rotate. The work is absorbed by direct connection to a centrifugal pump circulating cooling tower water.

A great many compression plants have constructed double pipe tubes in which the high pressure gas expands through a nozzle. Almost without exception the cooling effect is so small as to give practically no precipitation of gasoline. The impossibility of expanding gas adiabatically through a nozzle is well understood and it is never possible to affect any great temperature reduction. In order to obtain a lowering in temperature the expanding gas must be forced to do some mechanical work.

Undoubtedly the use of expansion engines in recovering
Table #5.

GASOLINE CONTENT OF RESIDUE GAS FROM ABSORPTION PLANTS.

<table>
<thead>
<tr>
<th>Location</th>
<th>Bartlesville</th>
<th>Cushing</th>
<th>Osage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity M cu. ft.</td>
<td>375</td>
<td>300</td>
<td>12,000</td>
</tr>
<tr>
<td>Production gal/day</td>
<td>800</td>
<td>800</td>
<td>1,750</td>
</tr>
<tr>
<td>Recovery gal/M</td>
<td>2.1</td>
<td>2.66</td>
<td>.146</td>
</tr>
<tr>
<td>Absorption Medium</td>
<td>Mineral Seal</td>
<td>Mineral Seal</td>
<td>Mineral Seal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Still</th>
<th>Temperature</th>
<th>243°F</th>
<th>210°</th>
<th>209°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>10#</td>
<td>Atmospheric</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kind of absorbers</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>and vertical Cap &amp; Bell</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure on Abs.</th>
<th>80#</th>
<th>5#</th>
<th>225#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Circulated gal/M</td>
<td>77</td>
<td>134</td>
<td>4.9</td>
</tr>
<tr>
<td>Temp. of oil</td>
<td>75</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>(Entering Absorbers)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Atmospheric Temp. (During Test)</th>
<th>69°F</th>
<th>45</th>
<th>78</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue Gas Gal/M</td>
<td>.054</td>
<td>.35</td>
<td>.034</td>
</tr>
<tr>
<td>% Extraction</td>
<td>97.0</td>
<td>87.</td>
<td>61.</td>
</tr>
</tbody>
</table>
gasoline from the residue gas is profitable in most cases, but the mechanical difficulties, high vapor pressures, large weathering losses of the "wild" condensate, have made the operators somewhat reluctant in constructing this installation.

The Refrigeration Process.

There have been some plants which have used the ordinary ammonia refrigeration machine for extraction of gasoline from the discharge gas from compression plants. This system consists essentially of three parts -- a refrigerator, a compression pump and a condenser. The refrigerator which consists of a coil or series of coils is connected to the suction side of the pump, and the delivery from the pump is connected to the condenser. Brine is cooled by the expansion of the ammonia and passes through double pipe coils, through which the residue gas also flows and the heat is interchanged. Heat from the compressed vapor is transferred to the cooling water in condenser and the vapor is converted into a liquid returning by the regulating valve to the refrigerator.

Recently considerable work has been done on the application of mechanical refrigeration to the extraction of natural gas gaso-
line. The most improved methods used are the direct contact processes using salt or calcium chloride brine and gasoline as the refrigeration medium.

Direct Contact Brine Method.

In this method, the gas to be treated, is introduced into the bottom of a vertical tower fitted with suitable baffling material. Over these baffles is sprayed the refrigeration liquid such as salt or calcium chloride brine, which comes in contact with the countercurrent gas, affording a very efficient cooling between gas and cooling agent. The gasoline suspended is condensed and is carried down with the brine. The mixture is lead into a separator where the gasoline rises to the top and is trapped off and the brine pumped through the brine cooler to the scrubber again. The moisture in the gas is absorbed by the brine which results in a gradual dilution, which must be concentrated by steam coils. There is also an opportunity for freezing up of liquid on the baffles. To overcome this disadvantage gasoline is used as the refrigerative agent.

Direct Contact Gasoline Process.

This process is very similar to the method described
above with the exception that gasoline is used as the refrigeration agent and the increase in volume is trapped to storage or blending tanks. The layout of such an installation is shown in Fig. 6. Two towers are installed and used intermittently in case water freezes up on the baffles. If such occurs the gas and gasoline are by-passed to the other scrubber and compressed ammonia instead of the expanding ammonia is lead into the coils in towers to thaw out the ice.

A plant in Osage County of Oklahoma operating on the residue gas from the compression plant, gave the following results for the month of September:

<table>
<thead>
<tr>
<th>Operating Pressure</th>
<th>250 pounds per sq. inch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of Gas</td>
<td>20°F.</td>
</tr>
<tr>
<td>Production daily average</td>
<td>310 gallons(Refrigeration)</td>
</tr>
<tr>
<td>Production daily average</td>
<td>2000 gallons (compression)</td>
</tr>
<tr>
<td>Gas treated daily average</td>
<td>706,316 cu. ft.</td>
</tr>
<tr>
<td>Recovery daily average</td>
<td>.44 gallons per M. Cu. Feet.</td>
</tr>
</tbody>
</table>

The great advantage of the refrigeration process is the slower weathering and consequently a sharper separation between the permanent gases dissolved and compressed in the condensate, and the liquid fractions. The cold product will gradually liberate the dissolved gases and wild fraction if it is permitted to slowly warm up. (This effect will be nil if large storage tanks are used.) The disadvantages are initial costs, cost of operation and possibilities of...
lasing ammonia which is especially true when using the typical corrosive oil field waters over the cooling coils. Detailed description of California plants using this system has been described in another Bureau publication*.


Refrigeration Applied to the Absorption Process.

Probably the brightest future for refrigeration methods in the natural gas gasoline industry methods is its application to the absorption process. It is undoubtedly beneficial to cool the absorbing menstrum as a large number of plants run with oil of too high a temperature. It is not a rare case in which oil is found entering the absorption towers at 100°F in cool weather. By cooling the absorption medium the gasoline saturations may be run much higher with obvious advantages, of using less oil in the system resulting in low steam consumption and smaller plant equipment, and much easier distilling process with invariably lower end point of distilled product. By using artificial cooling the operation of the plant becomes independent of temperature conditions and more flexible as one of the (valuable) factors has been reduced to a constant.
Operation of Absorption Plants Treating Residue Gas.

In all cases vertical towers ever are recommended over horizontal absorbers. Higher extraction efficiency, less circulating oil, higher saturation of absorbing medium, lower initial and operation costs are the merits of the absorption towers. It is possible to procure as high as 95% recovery efficiency with vertical scrubbers, taking the extraction as determined by the small portable absorbers as 100%.

Details of typical absorption towers are shown in Figures 7, 8 and 9. The diameters of towers vary from 12 inches to 36-inches and the height should not be less than 30 feet. In a recently designed plant, the absorbers are 42 feet and practice is tending towards this direction. Factors regulating the size of the absorbers are pressure, flow velocity of gas and voidage of baffling material. Capacities of absorbers should be such that the linear velocity of gas should not exceed 150 feet per minute in the baffled portion of towers.*

* W. P. Dykema, Bulletin 176, Bureau of Mines (In press)
Bill of Material for Absorber Shown in Fig. 7.

Blending Tower for Gasinghead Gasoline Plant.

A-Detail of gasoline inlet, same for gas outlet; B, detail of naphtha inlet; C, detail of method for holding perforated plates in place. (Parts are numbered as in table on page...)

1, Cover plate; 2, 1-inch gate valve (not shown); 3, 3/4-inch gate valve for water drain; 4, 3/8-inch gate valve; 5, 2-inch ell; 6, 1-inch ell; 7, 1-inch tee; 8, 3/8-inch ell; 9, 2-inch union; 10, 1-inch union; 11, 2-inch collar, welded; 12, 1-inch collar, welded; 13, 2-inch by 12-inch nipple (not shown);
14, 2-inch by 6-inch nipple; 15, 1 1/2 by 12-inch perforated nipple, with four welded end, 1/4 rows of 3/16-inch holes, 16 in a row, 1/2-inch pitch, drilled in bottom of nipple; 16, 3/8-inch by 12-inch perforated nipple with welded end, two rows of 1/8-inch, 8 in row, 1/2-inch pitch drilled in bottom (perforated nipples are welded to outside pipes and inserted through screwed collar); 17, 1-inch by 6-inch nipple (not shown);
18, 3/4-inch by 4-inch nipple (not shown); 19, 3/4-inch by 3-inch nipple (not shown); 20, 2 by 1 by 12-inch swing nipple at gasoline outlet; 21, 15-inch perforated plates, 3/8 inch thick, lower plate drilled.
with 120 1-inch holes, upper plate, 480 \( \frac{3}{4} \)-inch holes; 22, 15-inch plate, \( \frac{3}{4} \) inch thick, welded to rods; 23, 15\( \frac{1}{2} \)-inch casing; 24, 2-inch pipe; 25, 1-inch pipe - 26, tile; 27, 1-inch rods, welded; 28, set screws (not shown); 29, pressure gage, 500-pound pressure; 30, gases; 31, welded seal (not shown); 32, 3/4-inch rods; 33, 1-inch lug, welded.

Figure 8- Plan of Absorption Tower Showing Piping and Connections.

a, Gas traps, 400-pound pressure; b, 3-inch line to W tank, 50 pound pressure; c, \( \frac{1}{2} \)-inch line from trap; d, 3-inch by-pass, 400-pound pressure; e, 2-inch oil line, 400 pounds; f, 2-inch by-pass; g, thermometer wells; h, 4-inch gas header, 400 pounds; i, absorption towers 400 pounds; j, 6-inch gas header, 400 pounds.
Explanation of Details of Scrubber shown in Figure 9.

End Elevation of Absorption Tower.

A, Detail of gas inlet and gas outlet connections; B, alternative method of making gas inlet and gas outlet; C, detail of oil inlet connection; D, detail of method for holding plate. 1, Cover plate; 2, 4-inch gate valve; 3, 2-inch gate valve; 4, \( \frac{3}{4} \)" gate valve; 5, 2-inch tee; 6, 2-inch ell; 7, \( \frac{3}{8} \)" ell; 8, 4 inch screw collar; 9 2-inch screw collar; 10, union; 11, \( \frac{1}{2} \) inch plate, perforated (50 per cent of area) \( \frac{1}{2} \)-inch holes or larger; 11a, 1-inch lugs; 12, perforated plate; 12a, seven 1-inch rods welded to pipe; 13, supporting rods; 14, tile; 15, \( 3\frac{1}{2} \times 26 \) inch perforated nipple, welded to 4-inch pipe, 4 rows of \( \frac{1}{2} \)-inch holes, 16 in row, 1\( \frac{1}{2} \) inch pitch; 16, 1\( \frac{1}{2} \) inch perforated nipple welded to 2-inch pipe; 2 rows of 1/8 inch holes, 16 in a row, 1\( \frac{1}{2} \) inch pitch; 17, 4-inch by 6-inch pipe nipple; 18, 4-inch close nipple; 19, 2-inch by 6-inch/nipple; 20, 2-inch close nipple; 21, 2-inch flange union; 22, pressure gage; 23, 30-inch casing; 24, 4-inch pipe; 25, 2" pipe; 26, \( \frac{3}{4} \)-inch by 3-inch nipple; 27, 1-inch gate valve; 28, 1-inch collar; 29, 1" by 4" nipple; 30, sampling value; 31, gages,
32, 3/4 inch reinforcing rods, 8 feet long; 33, 3/4-inch bars, 2-ft
long; 34, leg of supports; 35, 1-inch U-bolts; 36, gas meter on main
line (not shown); 37, 18-inch headers, supported at intermediate points
by pipe columns, spaced 10 feet apart; 38, support for header; 39,
oil meter on main line; 40, header, 41, concrete base for pipe support.

-- Baffles --

Paramount in importance is the proper choice of a
suitable baffling material or tower packing. The factors to be consider-
ed in determining what shall be used, is surface exposed by packing, weight
per unit volume, voidage, likelihood of channelling and if material will
have any deliterious effects on other working parts of plant such as gett-
ing rust into the traps or finely divided dust in the absorption medium
thereby fostering the formation of an oil-water emulsions which are sometimes
very troublesome and difficult to handle.

Some of the factors (average) of typical tower packing is
recorded in Table #6. Ordinary **steel shavings** give a large voidage
and surface exposed but have the disadvantage of settling rapidly, corrod-
ing (especially with casinghead gas which sometimes contains as much as

- 43 -
| Baffling Material.  
| Table # 6.  

<table>
<thead>
<tr>
<th>Weight per cu. ft. Lbs.</th>
<th>Surface exposed Sq. ft / cu. ft.</th>
<th>Voidage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raschig Rings</td>
<td>35#</td>
<td>60</td>
</tr>
<tr>
<td>4 x 3 clay tubes</td>
<td>112#</td>
<td>32</td>
</tr>
<tr>
<td>Steel Shavings</td>
<td>57</td>
<td>—</td>
</tr>
<tr>
<td>Crushed Rock</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>Lathing</td>
<td>15#</td>
<td>22</td>
</tr>
</tbody>
</table>
50% air besides some salt water) and tendency to be carried over into the traps, valves on pipe lines and valves in the pumps.

Crushed rock should not be used as the voidage is too small. A tower filled with steel shavings will handle more than two vertical absorbers filled with ordinary crushed rock.

One company in the Mid-Continent field is using clay curved partition rings 4" by 3" which are used quite extensively in the acid and alkali industries. This packing has some disadvantages as the crushed rock in giving small free passage for gas and in addition cannot be placed in the tower at random without forming free spaced through which the oil will channel and result in not bringing oil and gas into intimate contact.

Wooden lathes have proven successful in many plants and very efficient if care is taken in their construction. The baffling is usually made of lattice work and all the boards should be planed in order to eliminate any possibility of splinters getting over into the traps of valves. Attention should be given to the design in order that the oil will not channel, particularly around the edges of the tower.
A plant in Louisiana uses baffle plates, welded into the tower, that are perforated with 1/64 inch holes. The voidage is about 50%. Great trouble is encountered due to loss of oil in a fine mist which cannot be caught by any separator or drip which has been installed. The small holes break the oil into too small divisions which gives the oil a spray effect.

Raschig rings seem to be the best tower packing which has been examined. They are made of glazed clay, 1-inch long and 1-inch in diameter, being 1/8-inch thick and only weighing 35 pounds, per cubic foot. They give 60 square feet of exposed surface per cubic foot with 70% voidage and can be thrown into the tower at random without the forming free places for channeling.

Oil Rates.

The quantity of oil circulated will depend upon pressure of gas, temperature of oil, mechanical arrangement of absorber and baffling material, and characteristics of gas which cannot be overlooked.

In all cases a smaller quantity of oil is required in a
vertical tower than in horizontal absorbers. The more uniformly distributed and the more surface exposed, the smaller will be the amount of oil necessary for efficient extraction of the lighter hydrocarbons, and this must be borne in mind when choosing a tower packing.

On the account of the different characteristics of each individual gas, no table can be accurate in giving the quantity of oil in gallons per thousand cubic feet of gas, which is necessary for complete recovery of the gasoline in gas, and depending upon the pressure and gasoline content of gas. There is an example of two gases in Southern Kansas which contain approximately .20 gallons of gasoline per thousand cubic feet of gas and when treated in exactly the same vertical absorber and at the same pressure, the saturation of absorption menstrum can be allowed to raise as high as 9.0%, while the other gas the efficiency of extraction decreases after the saturation of oil passes 4.0%.

One should endeavor to regulate the quantity of circulating oil in order to get the highest saturation, which gives the economic maximum efficiency in absorption. With treated absorption oil of high saturation of gasoline, the cost of the distillation process is less
Illustration #7.
Typical Steam Still for Stripping Absorption Oil.

Illustration #10.
Knock-out Box in Which Constant Level of Water at Constant Temperature is Maintained. (pp. 58)
and a better product, particularly as regards the end point characteristic, is obtained.

**Still Operations.**

There are two types of stills in general use in the absorption practice. One which contains a large quantity of oil and heated by steam from open coils entirely or a combination of steam from open and closed coils. Various systems of baffling are used in order to lengthen the time which oil remains in the still. The other type contains a series of pans filled with closed coils into which the treated oil flows, only a small amount of oil is maintained in the bottom of the still and this is heated by direct steam. The capacities of this still arrangement is very large compared with the "tub" still. An ordinary still constructed so that oil can be heated by direct and closed coils is shown in illustrations #7. For detailed information regarding the construction of stills, reference should be made to the Bureau of Mines publications.

Troubles may be experienced by the application of the absorption system to the residue gas from compression plants if mineral seal oil instead of naphtha is used as the absorption medium which is not ordinarily encountered in the usual absorption practice. The gas will contain large quantities of propane and butane which are permanent gases under standard conditions, which dissolve in the absorption medium quite readily. During the distillation stage these gases will be liberated with liquid hydrocarbons and consequently result in a loss of stable gasoline at the look box. Regardless how cold the condensers may be the permanent gases will carry away some of the gasoline but the colder the condenser the lower will be the partial vapor pressure of the liquid components which governs the quantity of gasoline in tail house vapors.

There are several methods of offsetting this difficulty, to a certain extent. One method is to condense gasoline under pressure say of about 10 pounds, and increase the temperature of still to about 245 degrees F. Another means is suggested by adding naphtha to the absorption oil after it has been treated in the scrubbers. The add-
ition of about 2 percent naphtha will materially decrease the
volatilization losses and if high grade naphtha is used, will give a
very satisfactory endpoint. For an example, assume that the still vapors
contain equal volumes of butane (B.P. plus 33°F) and hexane (B.P. 156°F)
and that condensation is taking place at 60°F and atmospheric pressure.

At 60°F one cubic foot of gaseous hexane is equivalent
to 156 cc of liquid hexane which has a vapor pressure of two pounds.

The vapor pressure of butane is 30 pounds under the above conditions
and consequently will not condense under assumed conditions. At
the look box, the hexane will be carried away by the butane in a mix-
ture which contains 2/15 by volume of gaseous hexane or 21 cc of hexane
will evaporate and be carried away in each cubic foot of tail gas.

Now if an equal volume (156 cc) of naphtha is added to the hexane
before entering the still the partial vapor pressure of hexane before
entering the will be reduced to 1-pound and only 10.5 cc of hexane
will be uncondensed with a net saving of 50%. These deduc-
tions are made on the assumption that no butane is dissolved in the
hexane and that both gases following the gas laws at 60°F. From these
Illustration 8
Knock-out box with Thermostatic Valve Control.

Illustration 9.
Primary Condenser circulating water continuously.
data it is obvious that the addition of naphtha will give beneficial results.

In all cases the economic maximum saturation of the absorbing oil should be attained as with higher saturations the distillations losses will be less.

**Knockout Boxes or Primary Condensers.**

Most absorption plants are equipped with primary condensers to knockout the heavier hydrocarbons or tops of the mineral seal oil. Absorption gasoline usually demands a premium on the gasoline market which is primarily contingent upon the end point of the product. Illustration 8 shows a knockout box which is maintained at 190°F by water sprays governed by a thermostatic valve. Illustration 9 is practically the same with the exception of the thermostatic valve. Illustration #10 shows a primary condenser which is partly filled with water maintained at a temperature of 182°F through which the still vapors pass. The heavy ends that collect in these devices are returned to the still.

**Feasibility of Installation.**

The writers is not unmindful of various conditions exist-
ing in different fields and different plants and consequently does not state that the application of the absorption system to the residue gas from compression plants extracting gasoline from natural gas will universally prove remunerative.

Thorough absorption texts should be made on the residue gas under the average prevailing conditions and in this preliminary examination dilution of casinghead gas by air or dry gas should be corrected before the final decision has been reached as to the feasibility of installing the absorption process.

Naphtha is recommended as the absorption medium wherever possible. Most casinghead operators blend their compression condensate with naphtha at plants before shipping, and the naphtha after passing through the absorber may be blended still more with the raw compression condensate if a higher gravity is desired. If the plant is located near a retail market the naphtha which has been used in the absorbers can be sold to the local trade.

An operator who installed an absorption system on the residue gas upon recommendation states:
"We were handling about 500,000 cubic feet of gas per day
and were recovering on an average of about 700 gallons of 69°Be. gravity
gasoline. We installed an absorber at a cost of $800.00 through which we
are now running our residue gas. We are recovering a minimum of 50
gallons and as high as 250 gallons per day of high grade gasoline from
this absorber. In addition to this we are using from 500 to 800 gallons
of 50-58 naphtha as an absorber and are increasing the gravity to 59-61.
The increased value added to this naphtha, together with the quantity
of gasoline recovered, confirms your prediction that this plant as well
as practically all other compression plants in the Mid-Continent field,
is not obtaining proper efficiency in the extraction of gasoline from
the gas."

A fact which should not be overlooked, when contemplating
the installation of an absorption system in conjunction with a com-
pression plant, is that such an arrangement will make the compression
process far more flexible. If engine or compressor trouble is encoun-
tered, the plant can be run at reduced pressures with the absorption system
recovering the gasoline which would ordinarily be condensed in the
accumulators. The vapors from storage tanks can be treated in the absorbers with no fear of making the gas in the compression system "wild" by reworking through compressors.

During the year 1917, an average of 79,527,523* cubic feet of gas was treated daily by the compression process. If all the residue gas from the compression plants had been treated by absorption methods (Assumption residue gas contains .4 gallons per thousand cubic feet.) there would have been a daily saving of 31,611 gallons of gasoline or annual production of 11,611,015 gallons of gasoline.

<table>
<thead>
<tr>
<th>Volume (gal)</th>
<th>Weight (lbs)</th>
<th>Density (lb/ft³)</th>
<th>Specific Gravity</th>
<th>Zeros</th>
<th>Mass (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1200</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>1230</td>
</tr>
<tr>
<td>2000</td>
<td>2400</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>2260</td>
</tr>
<tr>
<td>3000</td>
<td>3600</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>3290</td>
</tr>
</tbody>
</table>

**Table 2**

<table>
<thead>
<tr>
<th>Volume (gal)</th>
<th>Weight (lbs)</th>
<th>Density (lb/ft³)</th>
<th>Specific Gravity</th>
<th>Zeros</th>
<th>Mass (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1200</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>1230</td>
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<tr>
<td>2000</td>
<td>2400</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>2260</td>
</tr>
<tr>
<td>3000</td>
<td>3600</td>
<td>0.85</td>
<td>0.70</td>
<td>0.75</td>
<td>3290</td>
</tr>
</tbody>
</table>