UNIVERSIDAD CATOLICA ANDRES BELLO
FACULTAD DE INGENIERIA
ESCUELA DE INGENIERIA INDUSTRIAL

Análisis y Propuestas de Mejora en las Áreas de Seguridad, Higiene y Ambiente en un Planta de Almacenamiento y Distribución de Hidrocarburos

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1
APERTURA DE LA INDUSTRIA PETROLERA
Mar Caribe
SAMSON
VEPICA
PETROLAGO
ING. 5020
PENNZOIL
VINCCLER
Maracaibo
CHEVRON
OCCIDENT
SHELL
Caracas
San Carlos
Barinas
TECPETROL
COREX
WASCANA
NOMECO
MOBIL
VEBA
NIPPON
ELF
CONOCO
PEREZ COMPANC
TECPETROL
ASTRA
AMPOLEX
SIPETROL
TOTAL
AMOCO
MAXUS
BP
OTEPI
BP
AMOCO
MAXUS
CONOCO
ENRON
INELECTRA
BP
AMOCO
Barcelona
MOSBACHER
TEIKOKU
Maturín
BENTON
VINCCLER
BENTON
NORCEN
NORCEN
PEREZ
COMPANC
COROD
LAGOVEN-MOBIL
VEBA
BITOR
CONOCO
STATOIL
JANDIS
MARAVEN-TOTAL
STATOIL-NORSK.H.
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CORPOVEN-ARCO
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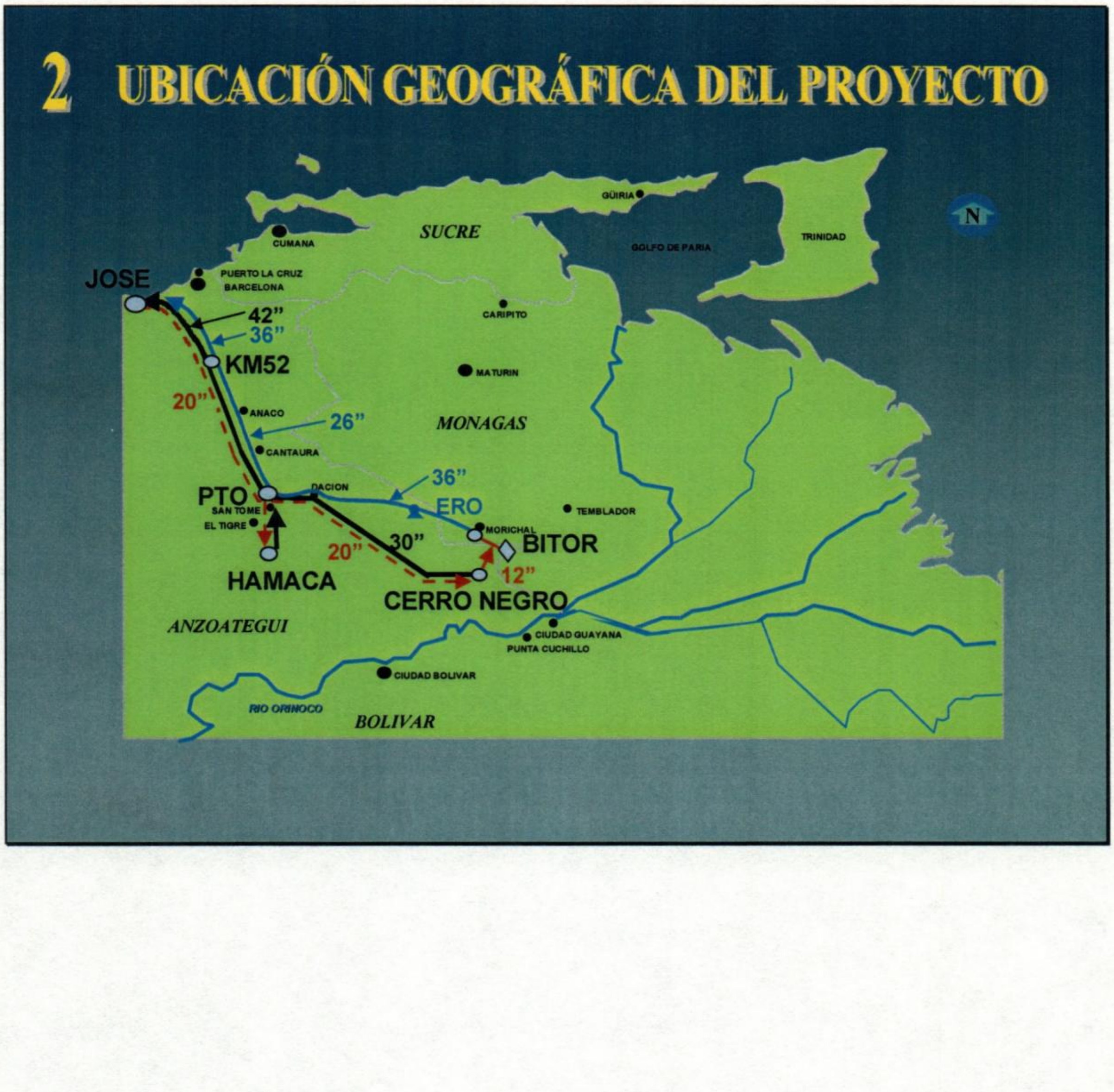
4 ASOCIACIONES ESTRATEGICAS
1 ORIMULSION TM (MTONS / AÑO)
8 ESQUEMA DE GANACIAS COMPARTIDAS
15 CONTRATOS SERVICIOS OPERACIONALES
18 TERCERA RONDA DE ACUERDOS OPERACIONALES

ANEXO N° 2


2 UBICACIÓN GEOGRÁFICA DEL PROYECTO
GÜIRIA
SUCRE
CUMANA
GOLFO DE PARIA
TRINIDAD
N
JOSE
PUERTO LA CRUZ
BARCELONA
42"
36"
CARIPITO
KM52
MATURIN
20"
ANACO
26"
MONAGAS
CANTAURA
36"
DACION
PTO
SAN TOME
EL TIGRE
ERO
TEMBLADOR
MORICHAL
BITOR
20"
30"
12"
HAMACA
CERRO NEGRO
ANZOATEGUI
CIUDAD GUAYANA
PUNTA CUCHILLO
CIUDAD BOLIVAR
RIO ORINOCO
BOLIVAR

ANEXO N° 3


3 ESTRUCTURA DE LA ASOCIACIÓN
MOBIL CERRO NEGRO
PDVSA CERRO NEGRO
VEBA OEL VENEZUELA ORINOCO
INTERESES MANCOMUNADOS
MOBIL C. NEGRO
PDVSA C. NEGRO
VEBA OEL VENEZUELA ORINOCO
PETROLERA C. NEGRO
OPERADORA C. NEGRO
MOBIL LTD

ANEXO N° 4

Sistema de Oleoductos

El sistema de oleoductos conectará las facilidades de producción con la planta de mejoramiento en Jose, estará formado por 2 líneas paralelas cada una de 315 Km de longitud. La "Tubería de Diluente" transportará diluente desde Jose al CPF y la "Tubería de Crudo" transportará crudo desde las Instalaciones de Campo hasta Jose.

El diluente reducirá la viscosidad del crudo pesado y su gravedad de 8,5° API hasta una gravedad de aproximadamente 16,6° API para permitir su bombeo y transporte. La tubería de diluente constará de dos segmentos:

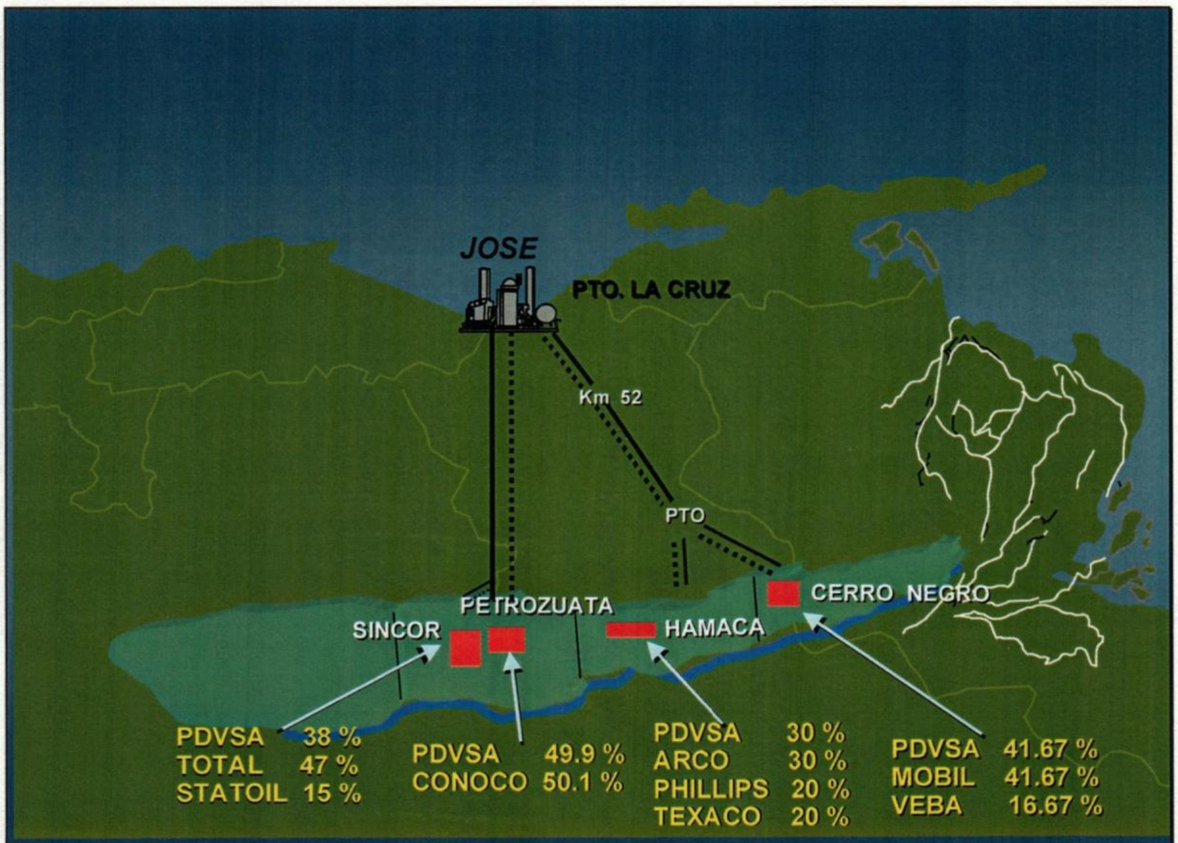
- El primero entre Jose y el punto llamado Patio de Tanques Oficina (PTO) será de 175 Km de largo, y
- El segundo segmento desde el PTO hasta las Instalaciones de Campo con una longitud de 140 Km.

Ambos segmentos se construirán usando tuberías de 20", con el fin de proveer de diluente a otros proyectos en el área como por ejemplo el Proyecto Hamaca; puesto que los requerimientos originales de tubería del Proyecto son de 16" de diámetro desde Jose a PTO y de 12" entre PTO y las Facilidades de Campo, esto.

Durante la Fase de Producción de Desarrollo, el oleoducto de diluente transportará Oso Nigeriano o un sustituto apropiado desde Jose al CPF. Una vez iniciadas las actividades del mejorador, el crudo se procesará en él para obtener sincrudo, recuperándose del proceso nafta (derivado de petróleo con alta gravedad API) que se utilizará como diluente, una vez bombeado al Centro de Procesamiento de Crudo en el área de producción; de manera que se aprovechará la nafta, excepto en ciertos períodos de baja producción del mejorador.

Por otra parte, la tubería de crudo constará de un segmento de tubería de 30" de diámetro entre las instalaciones de campo en Cerro Negro y PTO (140 Km), un nuevo segmento recientemente construido por PDVSA P&G de 42" de diámetro entre PTO y el KM-52 (120 Km), y una última sección entre KM-52 y Jose de 42 pulgadas de diámetro (55 Km).

Para la tubería de crudo, el Proyecto ha obtenido los derechos para la conexión y uso de la tubería de 42" de diámetro entre PTO y Km-52, propiedad de PDVSA P&G. Las líneas de conexión desde el centro de procesamiento de crudo al PTO y desde el Km-52 a Jose serán propiedad del Proyecto, quien asumirá el diseño, construcción y operación de estas tuberías, que además tendrán dimensiones superiores a la capacidad requerida para permitir el uso del sistema por otros proyectos.



ANEXO N° 5

Planta de Mejoramiento

El centro de mejoramiento está diseñado para mejorar el petróleo crudo extra pesado que contiene asfaltenos, nitrógeno, componentes de azufre, y metales pesados, para producir un crudo sintético adecuado para los requerimientos en los procesos desarrollados en la Refinería Chalmette y en el Sistema de Refinería de Veba. Además separará el diluente, el cual será reciclado y enviado a las instalaciones de producción.

Los procesos principales involucrados son: desalación, destilación de crudo, coquificación retardada e hidrotratamiento de nafta, y como procesos complementarios se encuentran: regeneración de aminas, tratamiento de aguas agrias y recuperación de azufre.

El crudo diluido es desalado previamente antes de cualquier proceso con el objeto de proteger las unidades contra la corrosión. La unidad de destilación separará el diluente y algunos destilados del crudo desalado dejando el residuo largo a fondo del barril para la unidad de coquificación.

El mejoramiento está basado en el uso de la tecnología de coquificación retardada, el cual es un proceso de craqueo térmico que a partir de la fracción pesada alimentada a la unidad de coquificación retardada produce un rango de productos que incluye gases, gasóleos, nafta, destilados, carbón sólido (coque) y azufre.

A continuación se describen las principales unidades de proceso destacando sus capacidades, función, insumos y productos y la interrelación entre ellas.

1. *Unidad de Destilación Atmosférica*

Esta unidad será diseñada para procesar aproximadamente 149.000 BPD de crudo (16-17° API), constituido por una mezcla de crudo cerro negro (77%) con nafta (23%).

Las principales funciones de esta unidad son: recuperar la nafta que se utiliza como diluente para ser reciclada hacia el campo de producción, y preparar la alimentación de la unidad de coquificación retardada. Esto es realizado en una sencilla torre de destilación que opera cerca de la presión atmosférica

El crudo diluido es precalentado con algunas corrientes de proceso, antes de someterlo a la etapa final de deshidratación y desalación para remover residuos de agua y sal en el crudo. Mediante un horno el crudo es calentado hasta 700 °F antes de ser alimentado a la torre de destilación atmosférica para su separación en los siguientes subproductos:

- Gas
- Nafta (C_5 – 380 °F)
- Kerosene / diesel (380 – 630 °F)
- Gasóleo liviano / pesado (630 – 740 °F)
- Residuo atmosférico (740 °F +)

El gas es enviado a la planta de gas integrada a la unidad de coquificación retardada, para su procesamiento y posterior uso como combustible de hornos y calderas. La nafta es almacenada en tanques, para su envío al CPF. Aproximadamente el 50% del residuo atmosférico se alimenta a la unidad de coquificación retardada. El resto se mezcla con los otros destilados obtenidos y se utiliza en la preparación del crudo mejorado de exportación.

2. *Unidad de Coquificación Retardada*

Esta unidad procesará 48.000 BPD de residuos provenientes de la unidad de destilación atmosférica. La función de esta unidad es convertir el residuo atmosférico en otros productos que permitan mejorar la calidad del crudo de exportación, aumentando así su valor comercial. Este proceso de craqueo térmico convierte el 64% (en peso) de la alimentación en productos líquidos, 8% en gas y el 28% restante en carbón sólido.

El residuo es sometido a un calentamiento rápido en el horno de la unidad hasta llevarlo a 925 °F, y luego es enviado a los tambores de coque donde se completa el craqueo térmico iniciado en el horno, convirtiendo el líquido en coque y vapores hidrocarbonados. La unidad consta de 4 tambores y 2 hornos, y el proceso de coquificación se realiza en ciclos de 18 horas para la deposición del coque y 18 horas para cortar y remover el coque de los tambores, lo cual resulta en un ciclo total de 36 horas para cada tambor.

Los subproductos obtenidos en esta unidad son: gas, nafta, destilado liviano y gasóleos pesados. El gas y la nafta producidos son enviados a la planta de gas donde todo el gas es tratado con aminas para remover los compuestos de azufre, y luego es enviado al sistema de gas combustible del mejorador. La nafta por su parte, es estabilizada mediante la remoción de los hidrocarburos livianos, y luego es enviada a la unidad de hidrotratamiento para mejorar su calidad. Los destilados y gasóleos producidos son utilizados directamente en la preparación de crudo mejorado de exportación.

Durante el ciclo de remoción de coque de los tambores, éste es enfriado y luego sometido a un proceso de corte con agua a alta presión dentro de los tambores. Coque en trozos y agua salen por la sección inferior de los tambores hacia la fosa de almacenaje de la unidad. El agua es continuamente recuperada y tratada para su reutilización en el proceso de corte del coque que luego es transportado en camiones desde la planta hasta el patio de almacenaje de coque del Complejo Industrial de Jose, el cual se encuentra adyacente al muelle de carga.

3. *Unidad de Hidrotratamiento de Nafta*

Esta unidad tendrá una capacidad de 6.000 BPD en términos de nafta craqueada; tiene como función principal saturar con hidrógeno los compuestos altamente inestables y formadores de gomas y residuos, como olefinas y diolefinas, esto permite prevenir la formación de sedimentos durante la preparación del crudo mejorado y durante su almacenaje, transporte y posterior reprocesamiento en las refinerías de destino. Adicionalmente, removerá el 95% del azufre total presente en la nafta, de manera que el proceso contará con dos etapas de reacción; la primera consiste en un reactor de saturación de diolefinas y la segunda de desulfurización. La corriente de gas resultante es enviada a la planta de gas para su tratamiento con aminas, y su posterior empleo como gas combustible.

4. *Unidad de Purificación de Hidrógeno*

El hidrógeno requerido para el proceso de hidrotratamiento de la nafta se obtendrá mediante la purificación de una o más corrientes ricas en hidrógeno (70 – 80% de pureza). La tecnología a ser utilizada es una unidad paquete tipo PSA ("Pressure Swing Adsorption") con la cual se logra una corriente de hidrógeno con una pureza del orden de 99%.

La unidad PSA constituye un proceso no criogénico de separación de gases que opera mediante la adsorción y desorción selectiva de los componentes de la corriente. La unidad consiste en un par de tambores operando en ciclos alternados para lograr una operación contínua de separación. El agente secante-adsorbente es del tipo tamices moleculares de carbón o zeolita y es sometido a contínuas adsorciones y regeneraciones hasta agotarse. El proceso separa físicamente el hidrógeno de los compuestos más pesados e impurezas, los cuales son enviados al sistema de tratamiento del gas combustible en el gas de purga. El hidrógeno es comprimido y enviado a la unidad de hidrotratamiento de nafta.

5. *Unidad de Regeneración de Aminas*

Esta unidad, también conocida como recuperadora de gas ácido (gas rico en sulfuro de hidrógeno y amoníaco), tiene como función el despojamiento de compuestos sulfurosos y amoniacales de la amina utilizada para la limpieza y procesamiento del gas combustible del mejorador. Esta unidad tendrá capacidad para regenerar 29.000 BPD de Mono-Etanol-Amina (MEA) rica en compuestos sulfurosos y amoniacales.

La MEA rica es alimentada a una torre para despojarla de los compuestos sulfurosos y amoniacales, dando lugar a la corriente de gas ácido que se envía como alimentación a la planta de recuperación de azufre.

La MEA regenerada, también conocida como MEA pobre, una vez reacondicionada mediante su filtración y la adición de productos anticorrosivos y antiespumantes, es reutilizada en las torres de tratamiento para gas combustible de las unidades de hidrotratamiento de nafta y de la planta de gas del coquificador.

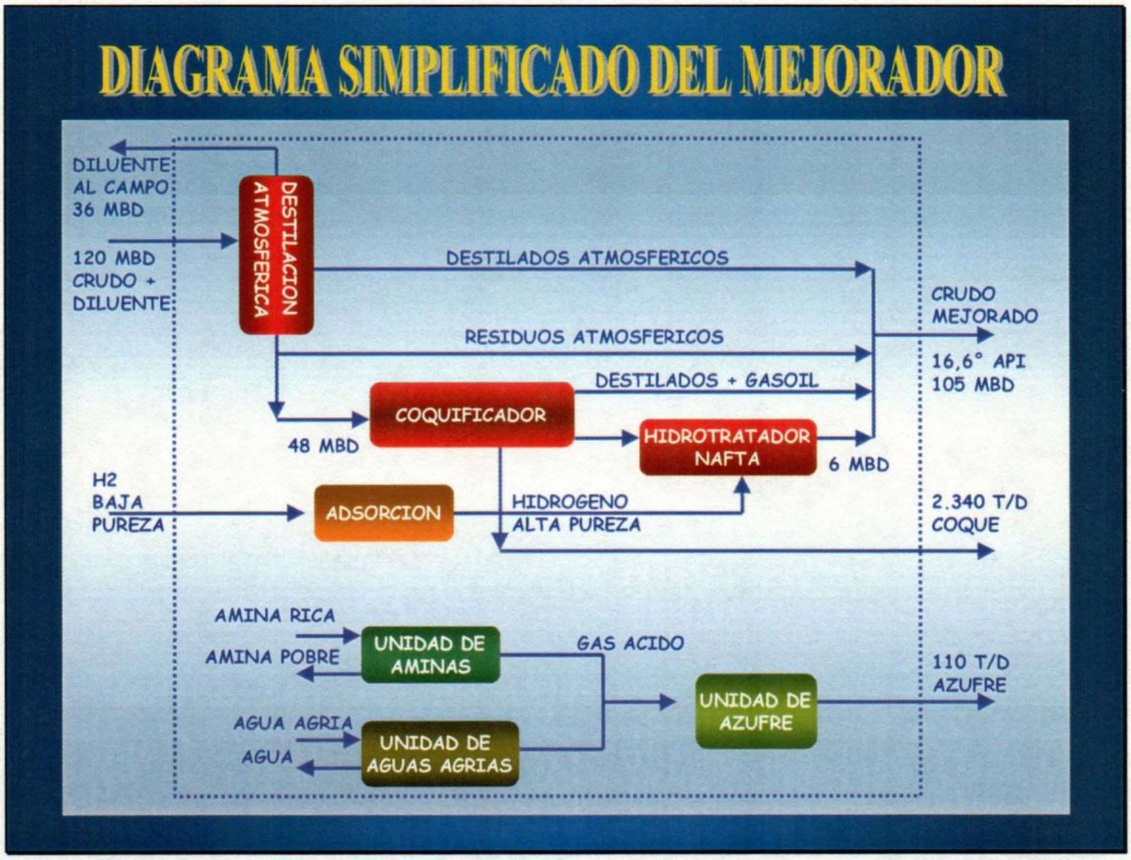
6. *Unidad de Tratamiento de Aguas Agrias*

Esta unidad consiste de una torre y un calentador, diseñados para despojar hasta 13.000 BPD de aguas agrias recolectadas de las diversas unidades del mejorador. El gas agrio (gas rico en sulfuro de hidrógeno y amoníaco) producido es enviado a las unidades de recuperación de azufre para su procesamiento. El agua despojada es reutilizada en las unidades de coquificación retardada, hidrotratamiento de naftas y destilación atmosférica.

7. *Unidades de Recuperación de Azufre*

El mejorador tiene dos unidades de azufre gemelas, cada una con capacidad para procesar la totalidad de los gases ácidos y agrios generados en la planta. Se estima recuperar 115 TMD de azufre elemental en estado líquido, mediante la conversión del sulfuro de hidrógeno (H_2S) presente en los gases ácidos y agrios. El azufre producido será desgasificado, almacenado y enviado a una unidad de solidficación antes de ser transportado en camiones hacia el área destinada para su exportación.

Seguidamente se presenta el diagrama simplificado del mejorador:



ANEXO N° 6

Facilidades de Carga

Las instalaciones de carga incluirán todos los sistemas necesarios para el transporte de productos líquidos y sólidos desde el almacenaje hasta el embarque. Las facilidades de carga constarán de: Instalaciones de Manejo de Líquidos e Instalaciones de Manejo de Sólidos.

- ### Instalaciones para el Manejo de Líquidos

  Las facilidades para el manejo de líquidos estarán situadas en el área de Jose y constarán de instalaciones de almacenamiento, plataforma de embarque y desembarque ubicada a 7,5 Km de la costa de Jose; tuberías submarinas que conectarán la plataforma y las instalaciones de almacenamiento y una estación de bombeo para cargar los barcos. Las facilidades para el manejo de líquidos estará capacitada para embarcar más de 800 MBD de crudo y recibir 20 MBD de diluente.

  Luego de la puesta en marcha del mejorador, el sincrudo será almacenado en tanques construidos en Jose, y bombeado a las instalaciones de manejo de líquidos para su exportación. Se espera concluya su construcción a mediados de 1999 para su uso durante la Fase de Producción de Desarrollo para la recepción del diluente y exportación del crudo diluido a las Refinerías de Chalmette y Ruhr Oel. Las operaciones de coordinación de las exportaciones y los movimientos de líquidos y sólidos a través de los diferentes terminales estarán a cargo del Agente Operadora Cerro Negro.

- ### Instalaciones para el Manejo de Sólidos

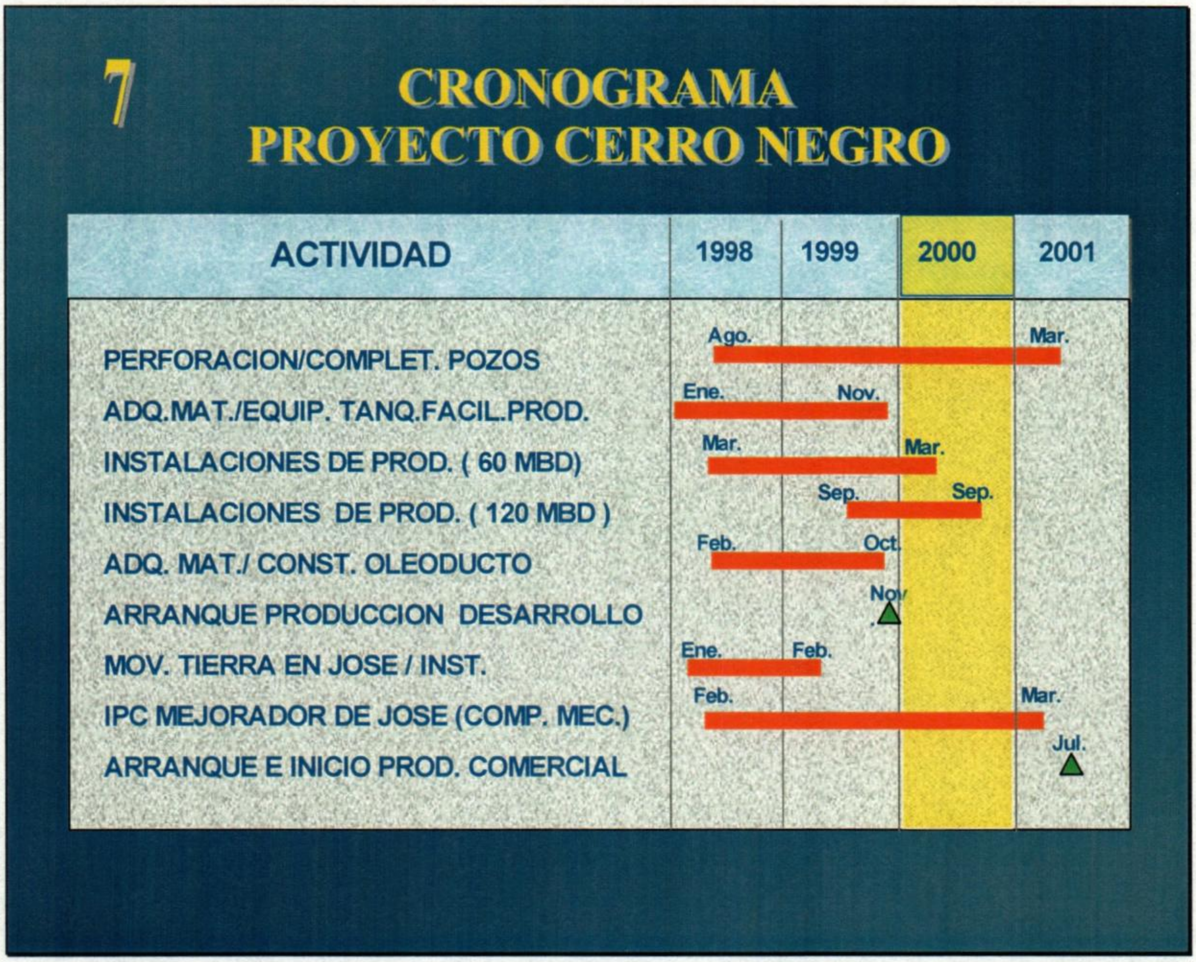
  El Proyecto usará las facilidades para manejo de sólidos construidas por Petrozuata en Jose, las cuales serán completadas a finales del año 2000. El coque y el azufre producido en el mejorador serán trasladados hasta dichas instalaciones por transporte terrestre, y mezclados con coque y azufre de calidad y características similares, producidas por otros usuarios de las instalaciones.

La capacidad del terminal se espera sea de aproximadamente 11.000 TPD, suficiente para adoptar los requerimientos de Petrozuata de aproximadamente 3.200 TPD de coque y 150 TPD de azufre, y los del Proyecto mismo de aproximadamente 2.040 TPD de coque y 110 TPD de azufre. Es importante destacar que se prevé un expansión en la capacidad del terminal por la inminente puesta en marcha del proyecto Hamaca, con lo cual se manejarían alrededor de 15.000 TPD de sólidos en lugar de las 11.000 TPD mencionadas anteriormente.

La siguiente tabla describe los volúmenes de sólidos de cada uno de los proyectos en la Faja del Orinoco:

PRODUCCIÓN COQUE	1999	2000	2001	2002	2003
Petrozuata	-	3.150	3.150	3.150	3.150
Sincor	-	-	-	4.960	4.960
Cerro Negro	-	-	2.340	2.340	2.340
Hamaca	-	-	-	4.500	4.500
Total Coque	-	3.150	5.490	14.950	14.950
PRODUCCIÓN AZUFRE					
Petrozuata	-	200	200	200	200
Sincor	-	-	-	1.000	1.000
Cerro Negro	-	-	115	115	115
Hamaca	-	-	-	600	600
Total Azufre	-	200	315	1.915	1.915

ANEXO N° 7


7
CRONOGRAMA
PROYECTO CERRO NEGRO
ACTIVIDAD
1998
1999
2000
2001
PERFORACION/COMPLET. POZOS
Ago.
Mar.
ADQ.MAT./EQUIP. TANQ.FACIL.PROD.
Ene.
Nov.
INSTALACIONES DE PROD. (60 MBD)
Mar.
Mar.
INSTALACIONES DE PROD. (120 MBD)
Sep.
Sep.
ADQ. MAT./ CONST. OLEODUCTO
Feb.
Oct.
ARRANQUE PRODUCCION DESARROLLO
Nov
MOV. TIERRA EN JOSE / INST.
Ene.
Feb.
IPC MEJORADOR DE JOSE (COMP. MEC.)
Feb.
Mar.
ARRANQUE E INICIO PROD. COMERCIAL
Jul.

CAPITULO 2

BASAMENTO CONCEPTUAL

ANEXO N° 1

DESCRIPCIÓN DE LOS PROYECTOS DE PRODUCCIÓN

- Perforación de exploración: Perforación de pozos en un área no probada con el propósito de encontrar nuevas reservas

- Perforación de desarrollo: Perforación dentro de un área probada de un yacimiento de petróleo o gas, a la profundidad de un horizonte o arena que se conoce como productiva

- Perforación de avanzada: Perforación con el propósito de delinear los límites geográficos de los yacimientos desarrollados

- Reacondicionamiento y recompletación de pozos: Comprende las actividades de reacondicionamiento y reparación de pozos.

  El reacondicionamiento implica cambios o modificaciones en los intervalos de producción o yacimientos, bien sea para normalizar el rendimiento de gas asociado, evitar demasiada producción de agua con nata o cambiar el horizonte abierto a la producción.

  Las reparaciones incluyen trabajos relacionados con el reemplazo de equipos del subsuelo y operaciones para corregir daños en el revestidor, sin cambiar de horizonte productor

- Recuperación secundaria: Comprende la inyección de gas y/o agua para mantener la presión y desplazar cantidades adicionales de petróleo del yacimiento

- Inyección alternada de vapor: Proceso térmico de recuperación mejorada durante el cual se procede a enviar vapor de agua al yacimiento en forma discontinua, pero regula. El calor del vapor introducido aumenta la temperatura del yacimiento y disminuye la viscosidad del petróleo, resultando así en un notable aumento de su movilidad y en las tasas de producción del crudo

- Levantamiento artificial por gas: Consiste en suministrar gas a elevada presión al pozo, para aumentar su aporte o inducirlo a producir cuando no es capaz de hacerlo. Este método es utilizado en Venezuela para producir crudos livianos medianos; sin embargo, el mismo ha tenido limitada aplicación para producir crudos pesados, debido principalmente al aumento de viscosidad del crudo por enfriamiento durante la expansión del gas

- Conservación y utilización del gas: Incluye sistemas de recolección y distribución de gas a los campos, plantas de compresión, etc., para utilización del gas e instalaciones para inyectar gas con el propósito de almacenarlos

- Plantas de gas licuado de petróleo (GLP): construcción de plantas para la producción de gas licuado de petróleo, el cual se encuentra formado por hidrocarburos de petróleo, los cuales son gaseosos a presión y temperatura ambiente, pero pueden ser licuados mediante la aplicación de presión para ser almacenados y transportados como líquidos. Adicionalmente incluye las instalaciones y equipos, para la extracción y fraccionamiento de líquidos del gas natural y licuefacción a baja temperatura

- Oleoductos y terminales: Comprende la construcción de tuberías para bombear hidrocarburos desde los tanques del sistema principal de almacenamiento hasta los tanques de almacenamiento en los terminales de embarque o hasta el punto de entrega en una refinería; así como también involucra la construcción de terminales de embarque requeridos para almacenar y embarcar hidrocarburos desde la entrada a los tanques de almacenamiento de los terminales, hasta los atracaderos de carga de los tanqueros. En otras palabras, incluye los costos de las instalaciones y líneas de recolección, líneas troncales, estaciones de bombeo, terminales de embarque, etc.

- Instalaciones de producción: Construcción de la planta a emplearse directamente en la producción o extracción de hidrocarburos, así como de la infraestructura de apoyo a las actividades de producción de petróleo o gas. Incluye los costos de equipar pozos de producción, el costo de instalación de estaciones recolectoras, unidades de separación a bajas temperaturas, instalaciones eléctricas secundarias, sistemas de gas combustible, carreteras menores de campo, sistemas de protección catódica, suministro de agua para las operaciones, etc.

- Protección ambiental: Actividad dirigida a la protección, conservación y mejoramiento del ambiente en las áreas operacionales. Incluye equipos de contención y recolección de derrames, sistemas de detección de fugas, instalaciones para eliminar humo, plantas para clarificar y tratar aguas, instalaciones para disponer de aguas, etc.

- Otras inversiones: Costo de instalaciones básicas que dan apoyo a las operaciones de producción de as y petróleo no incluidas en los renglones anteriores. Ejemplos: carreteras primarias, plantas eléctricas, aeropuertos, sistemas de comunicaciones, muelles de lanchas, puentes principales de transmisión de electricidad, etc.

ANEXO N° 2

Indicadores Económicos

Todo proceso de inversión genera un flujo de caja anual durante el horizonte económico establecido. Estos flujos de caja por si solos no ofrecen información fácilmente interpretable, por lo cual se han desarrollado una serie de fórmulas que permiten obtener unos indicadores económicos, cuyos resultados ofrecen una orientación acerca de la conveniencia económica de un proyecto.

- ### Valor Presente Neto (VPN)

  Conceptualmente, el "Valor Presente Neto" corresponde al valor actual de todos los flujos de efectivo neto (Ingresos – Egresos) determinados para una propuesta conforme su horizonte económico.

  Para calcular el valor actualizado del flujo de efectivo, éste se descuenta a una tasa de interés dada. La sumatoria de los flujos de efectivo descontados, que estructuran la propuesta, constituyen el Valor Presente Neto. Su expresión matemática es:

$$VPN = -A_0 + \sum_{n01}^{t} \frac{(-A_n + IT_n - CT_n)}{(1 + Td)^n}$$

donde:

A: Inversiones.

IT: Ingresos totales.

CT: Costos totales.

Desde el punto de vista de la evaluación económica de propuestas el valor presente neto corresponde a la diferencia entre el valor de la inversión, el cual por definición es un valor actual y la sumatoria de los flujos de efectivo de operación descontados a una tasa determinada.

Es así como el VPN corresponde al valor actual del dinero que se obtiene, por encima del monto mínimo esperado, al ejecutar un proyecto de inversión. El VPN puede considerarse el indicador de mayor certeza en la determinación de la oportunidad de invertir.

- ***Tasa Interna de Retorno (TIR):***

Se denomina tasa interna de retorno a la tasa de interes promedio que iguala que iguala el valor presente de una serir de ingresos y gastos con la inversión inicial; es decir, es aquella tasa de interés que hace el valor presente neto igual a cero. Desde el punto de vista de la evaluación económica de proyectos corresponde a la tasa que a través del descuento de los flujos de efectivo (actualización de los flujos) permite recuperar la inversión

Se utiliza cuando se desea obtener una indicación porcentual del rendimiento del proyecto que permita compararlo con el rendimiento de otros proyectos o instrumentos financieros. Matemáticamente se expresa como:

$$VPN = -A_0 + \sum_{n01}^{t} \frac{(-A_n + IT_n - CT_n)}{(1+TIR)^n} = 0$$

Para que un proyecto pueda considerarse atractivo utilizando el método de la TIR, el resultado de este indicador debe superar la tasa mínima de rendimiento exigida para el proyecto.

ANEXO N° 3

MÉTODOS PARA LA IDENTIFICACIÓN DE PELIGROS

- ***PHA METHODOLOGY***

The "What if?" methodology was chosen as the appropriate technique for this project to ensure a rigorous examination of process hazards, as well as potential operational problems that could propagate into "serious events.

"WHAT IF?" PHA STUDY TECHNIQUE

The "What if " analysis is a hazard analysis metbodology recognized by industry as an appropriate method for process hazard analyses. It is a thorough and systematic examination of operations and/or processes utilizmg a mulddisciplinary tearn of experienced personnel to review deviations from the design intent.

A series of nWhat if?" questions about the design and operation of the facility are asked and answered. All of the questions and answers are entered on a standardized form completed during the PHA sessions. The purpose of the analysis and report is to provide management with a tool to respond to all team findings and recommendations.

Questions are formulated in a "What if?" format on worksheets prior to the PHA session. Additional questions are generated by the team. The team discusses tbe potential causes and consequences of each item, including human error conditions, and the fmdings are recorded m the CAUSE and CONSEQUENCE.

Assumed failures of administrative controls (i.e., operatmg procedures, training, inspection, and maintenance programs, etc.) were grouped under general headings such as "operator error," ninstallation damage," Xcorrosion," etc., except for those cases in which the assumed failure could result m a potentially sigruEicant hazard. In such cases, the particular administrative control(s) mvolved are noted m abbreviated form-in parenthesis, or are listed in detail. In these cases, the reason for smgling out a given administrative control can normally be found in the RECOMMENDATION.

The existing protection is then discussed and recorded in the SAFEGUARDS. This category includes designed-in features such as instrumentation, alarms, shutdowns, relief valves, or automatic actions designed to mitigate the occurrence or consequence of potential hazards. Normal actions or response actions by operators can also provide protection.

Next, the team discusses whether current safeguards are adequate, or additional protection should be considered. If the team decides a change is warranted to improve safety or operability, this is noted in the RECOMMENDATIONS. In some cases further study is needed to evaluate a question, and a recommendatign for outside study is noted. PHA Study Action/Response Sheets are included to assist in tracking responses to recommendations generated by the team.

In this study, comments arose involving start-up and shutdown, since they are normal operating ftmstions for this facility. When suggested recommendations arose from these discussions, they were noted on the worksheets. The worksheets serve as the official record of the PHA sessions and are considered complete as to content once the PHA team adjourns and the sessions are concluded.

FACILITY SITING

The PHA team evaluated the relative location of equipment amd other components of the Central Production Facility. Since the equipment in this facility contains flammable hydrocarbons in sufficient quantities to warrant concern for operadons personnel, the proximity of nearby employee population centers (e.g., central control building, office building, and maintenance shop and warehouse) was considered.

The PHA team judged that the production facility appears to maintain adequate separation between process equipment (per IRI and Mobil spacing guidelines used as references by knowledgeable team members). The facility central control building is located approximately 200 feet to the northeast of the process equipment. The PHA team expressed concern that grade level releases could impact personnel in the building and recommended relocating all buildings further from the process equipment in accordance with the standards used at the Jose facility (with API RP 752 used as an additional resource).

The distance from withm the production facility to areas occupied by tbe general public is so great (over I - 2 miles) as to probably eliminate any risk to the public of exposure to potentially flammable vapors. The facility siting information was utiliied to qualitatively evaluate the potential consequences of specific accident scenarios proposed by the PHA team. Site-specific hazards and safeguards (e.g., access to emergency equipment, evacuation routes from the unit) were evaluated by the tearn to develop recommendations to protect operating personnel.

HUMAN FACTORS

During the Cerro Negro Project Proposed Scope PHA, in the analysis of each drawing, the PHA team identified several tasks of an operational nature which require operator interactions with process equipment. Many of these actions are representative of the types of tasks performed in the process area investigated and require the operator to interact with process control systems. One of the goals of the PHA was to identify and evaluate human equipment interactions that may lead to possible hazards. The actions may be operator errors, operator manipulations, failures, or ergonomic characteristics of the equipment in the Unit.

The PHA team included operations persomlel. They described the tasks required to operate the unit - those in the control room as well as those tasks completed on the specific pieces of equipment. PHA team members endeavored to become familiar with the layout of equipment and arrangement of process controls. The PHA team members evaluated equipment udlity and useability, and questdoned operations personnel to gain understanding of required operator tasks. Also, pieces of equipment were judged as adequate or inadequate with respect to the operator's normal work activity. The findings of the human factors review and recommended actions are included in the minutes of the PHA meedngs

RESULTS AND ACTIONS

The PHA discussion worksheets are presented because a potential process deviadon often will produce no or only insignificant consequences at the studied location, all questions discussed by the team were not fully recorded.

INTERPRETING THE WORKSHEETS

When reading the worksheets, the following points apply: There is not necessarily a correlation between any particular CAUSE and any particular CONSEQUENCE, or between a particular CONSEQUENCE and a particular SAFEGUARD, etc., unless specifically noted. Any of the causes may be associated with any of the consequences, safeguards, or recommendations. Consequences and safeguards could be associated with various causes, depending on severity.

There are some generic or universal causes for many process deviations. For example, pipe rupture upstream, blockage downstream, or plant off line could all cause No Flow at virtually any location. To avoid needless repetition, these generic causes are usually not listed. Failures of specific equipment or controls were listed where appropriate.

Some hazards, such as product contamination, could occur at virtually any location. Again, to avoid repetition, such a problem was not recorded for all drawings unless additional consequences could be uncovered.

Many P&ID correcdons were made during the ~What if?" meetings. These alterations were documented by Jantesa personnel without being recorded within the ~What if?" worksheets.

When the project contained two or more idendcal process trains, the PHA teatn analyzed one train; all comments (and recommendations) also apply to the other process trains.

A Guide to

HAZARD AND OPERABILITY STUDIES

Prepared initially in ICI and edited for
general industry use by representatives of
BP Chemicals Ltd
Chemical Industries Association Ltd
ICI Central Safety Dept
Shell Chemicals (UK) Ltd
under the aegis of the CISHEC Safety Committee.

Foreword

The Chemical Industry is an industry concerned with innovation. It produces a continual stream of new processes and products which sometimes involve working at extremes of temperature, pressure, scale of operation or of toxicity. Major changes lead in turn to a series of minor changes as knowledge increases and processes are optimised.

There is within the Industry great and growing awareness of the necessity to apply more systematic approaches to safety—particularly in plant design. In addition, there is increasing pressure from society at large for improved standards of safety.

Whenever something new is carried out there is the danger that some part of the process will not behave in the expected manner and that such a deviation could have serious effects on other parts of the process.

One technique designed to study such deviations is known as a *Hazard and Operability Study*. This is defined in the British Chemical Industry Safety Council publication *Safety Audits* in the following manner:

> *The application of a formal systematic critical examination to the process and engineering intentions of the new facilities to assess the hazard potential of mal-operation or malfunction of individual items of equipment and the consequential effects on the facility as a whole.*

The technique aims to stimulate the imagination of designers in a systematic way so that they can identify the potential hazards in a design. It is extremely flexible. It can be applied to all types of plant within the Industry ranging from large continuous ones such as petrochemical or ammonia plants, through small batch units to individual proprietary items of equipment such as autoclaves or machines for making sheets of plastic. The technique can be used by small organisations as well as by large ones.

This guide introduces the technique and has been written to give an appreciation of the method itself, its scope and its value.

Note on presentation

The sequence of chapters has been arranged firstly to convey the basic principles of the technique and then to place it in context.

The distinguishing feature of Hazard and Operability Studies is the 'Examinatior Session' during which a multi-disciplinary team systematically examines all relevan parts of a design using a structured but creative approach. As this is the key to the whole enterprise it is described first in a chapter devoted to the principles o examination.

Some preparative work is necessary before the examination and naturally there is follow-up work to deal with and document the hazards exposed. Chapter 3 deals with the practical procedures for carrying out a Hazard and Operability Study Hazard and Operability Studies are not an end in themselves but are part of ar overall procedure for the initiation, design, construction, commissioning and operation of facilities. Studies can be undertaken at various stages, the timing o which is discussed in chapter 4.

Further aspects are discussed in Appendices. The first three deal with practica applications including worked examples for various types of plant. Practical advic is given subsequently on how to make a start with Hazard and Operability Studies how to train people to carry them out and how to provide a continuing suppor for those engaged in them.

Contents

1 INTRODUCTION

Primarily, safety in the design of chemical plants relies on the application of various codes of practice or design codes which are based on the wide experience and knowledge of professional experts and specialists in the industry. Such application is backed up by the experience of local plant managers and engineers who have been involved in similar plants and who have had direct experience in their operation.

All new projects embody some element of change but in the chemical industry the degree of change from one plant to the next is often considerable. It is important to recognise that the body of established experience expressed in codes, etc is limited by the extent of existing knowledge and can only be relevant to the extent to which it is possible to apply it to new products, new plant and new methods of operation involved in the new design. It has become increasingly clear in recent years that although codes of practice are extremely valuable, it is particularly important to *supplement* them with an imaginative anticipation of hazards when new projects involve new technology.

The need to check designs for errors and omissions has been recognised for a long time, but this has traditionally been done on an individual basis. Experts have usually applied their special skills or experience to check particular aspects of design. For example the instrument engineer would check the control systems and having satisfied himself that the systems were satisfactory would put his mark of approval on the design and pass it to the next 'expert'. This kind of individual checking, provided it is carried out conscientiously, will obviously improve the design but clearly it has little chance of detecting hazards concerned with the interaction of a number of functions or specialisms. These hazards are likely to result from the unexpected interaction of seemingly safe components or methods of operation under exceptional conditions. If it is wished to study such interactions in new designs, the combined skills of a group of experts is required. Their total knowledge and informed imaginations can be used to anticipate whether the plant will operate as intended under all possible circumstances.

This report provides a method of working for such a group so that they can carry out their task systematically and thoroughly.

2 THE PRINCIPLES OF EXAMINATION

Because the examination procedure is the fundamental part of a Hazard and Operability Study, it is highlighted and described separately in this chapter.

2.1 The Basic Concept

Essentially the examination procedure takes a full description of the process, systematically questions every part of it to discover how deviations from the intention of the design can occur and decides whether these deviations can give rise to hazards.

The questioning is focussed in turn on every part of the design. Each part is subjected to a number of questions formulated around a number of *guide words* which are derived from method study techniques. In effect, the *guide words* are used to ensure that the questions, which are posed to test the integrity of each part of the design, will explore every conceivable way in which that design could deviate from the design intention. This usually produces a number of theoretical deviations and each deviation is then considered to decide how it could be caused and what would be the consequences.

Some of the causes may be unrealistic and so the derived consequences will be rejected as not meaningful. Some of the consequences may be trivial and would be considered no further. However, there may be some deviations with both causes that are conceivable and consequences that are potentially hazardous. These potential hazards are then noted for remedial action.

Having examined one part of the design and recorded any potential hazards associated with it, the study progresses to focus on the next part of the design. The examination is repeated until the whole plant has been studied.

The purpose of the examination is to identify all possible deviations from the way the design is expected to work and all the hazards associated with these deviations. In addition, some of the hazards can be resolved. If the solution is obvious and is not likely to cause adverse effects on other parts of the design, a decision can be taken and the design modified on the spot. This is not always possible—for example, it may be necessary to obtain further information. Thus the output from examinations normally consists of a mixture of decisions and questions for answering at subsequent meetings.

Although the approach as described may appear to generate many hypothetical deviations in a mechanistic way, the success or failure depends on four aspects

i The accuracy of drawings and other data used as the basis for the study
ii The technical skills and insights of the team
iii The ability of the team to use the approach *as an aid* to their imagination in visualising deviations, causes and consequences
iv The ability of the team to maintain a sense of proportion, particularly when assessing the seriousness of the hazards which are identified

Because the examination is so systematic and highly structured, it is necessary that those participating use certain terms in a precise and disciplined way. The most important of these terms are

Intention The *intention* defines how the part is expected to operate. This can take a number of forms and can be either descriptive or diagrammatic. In many cases it will be a flowsheet or line diagram. Other forms are described in section 3.3.

Deviations These are departures from the intention which are discovered by systematically applying the *guide words*.

Causes These are the reasons why *deviations* might occur. Once a *deviation* has been shown to have a conceivable or realistic cause, it can be treated as meaningful.

Consequences These are the results of the *deviations* should they occur.

Hazards These are *consequences* which can cause damage, injury or loss.

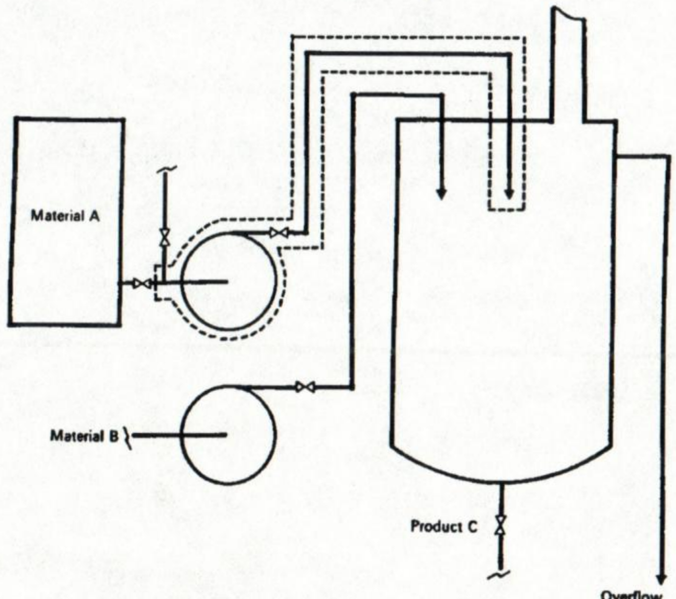
Guide Words These are simple words which are used to qualify the *intention* in order to guide and stimulate the creative thinking process and so discover *deviations*. A list of *guide words* is given in Table 1 (page 7).

2.2 A Simple Example

To illustrate the principles of the examination procedure, consider a plant in which chemicals A and B react together to form a product C. Let us suppose that the chemistry of the process is such that the concentration of raw material B must never exceed that of A otherwise an explosion may occur.

Referring to Figure 1 start, say, with the pipeline extending from the suction side of the pump which delivers raw material A to where it enters the reaction vessel.

Figure 1 AN EXAMPLE OF A SIMPLE FLOWSHEET



Reaction: A + B → C
Component B must not exceed Component A to avoid an explosion
The part of the plant examined is outlined thus ------------

The *intention* is partly described by the flowsheet and partly by the process control requirements to transfer A at some specified rate. The first *deviation* is that obtained by applying the *guide word* NOT, DON'T or NO to the *intention*. This is combined with the *intention* to give

DON'T TRANSFER A

The flowsheet is then examined to establish the *causes* which might produce a complete cessation of flow of A. These *causes* could be

i Supply tank is empty

ii Pump fails to turn—mechanical failure
—electrical failure
—pump is switched off, etc

iii Pipeline is fractured

iv Isolation valve is closed

Clearly some at least of these are conceivable *causes* and so we can say that this is a meaningful *deviation*.

Next we consider the *consequences*. Complete cessation of flow of A would very soon lead to an excess of B over A in the reaction vessel and consequently to a risk of explosion. We have therefore discovered a *hazard* in the design and this is noted for further consideration.

We now apply the next *guide word* which is MORE. The *deviation* is

MORE A IS PASSED INTO THE REACTION VESSEL

The *cause* would be that the characteristics of the pump may, under some circumstances, produce excessive flow rate. If this *cause* is accepted as realistic, we then consider the *consequences*

i The reaction produces C contaminated with an excess of A which goes on into the next stage of the process

ii The excess flow into the reaction vessel means that some will leave the vessel by the overflow

Further information will have to be obtained to decide whether these *consequences* would constitute a *hazard*.

The next *guide word* is LESS. The *deviation* is

LESS A IS PASSED INTO THE REACTION VESSEL

The *causes* are a little different from those when the *deviation* was the complete cessation of flow of A

i The isolation valve is slightly closed

ii The pipeline is partly blocked

iii The pump fails to produce full flow—because the impellers are eroded, or
—because valves are worn, etc

The *consequence* is similar to complete cessation of flow and so the potential *hazard* is of a possible explosion.

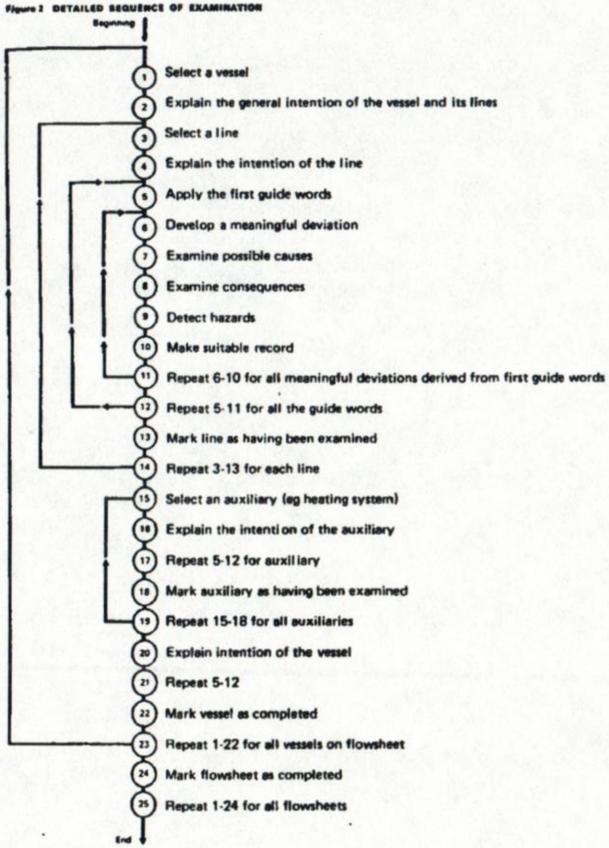
Four further *guide words* are in turn applied to the design *intention* of this part, to ensure that all conceivable *deviations* are explored.

When the pipeline which introduces raw material A has been examined, it is marked on the flowsheet as having been checked. The next part of the design is then chosen for study and this could be the pipeline which introduces raw material B into the reaction vessel. This sequence is repeated for every part of the design, each line, the vessel auxiliaries such as stirrers, any services to the vessel such as the provision of heating and cooling and the vessel itself. A chart of the sequence is given in Figure 2. This particular approach is sometimes called the 'line by line' method.

Only under exceptional circumstances is a written record made of every step of the examination. It is more usual to carry out the steps mentally and verbally in discussion and to write down only the potential *hazards* and their *causes*.

The proposed action is also noted if it can be agreed straight away. If there is some doubt about the action or if further information is required, the matter must be brought forward to a subsequent meeting.

Figure 2 DETAILED SEQUENCE OF EXAMINATION



2.3 Meanings of *guide words*

In the simple example we have demonstrated the principles of the examination method by showing how to apply the first three guide words. These are usually straightforward and produce easily-understood deviations. The remaining four guide words are not so easily applied and require some further explanation. Their meanings are now illustrated—again by reference to the example shown in Figure 1.

The next two deviations are both qualitative and all or part of the original design intention is retained. The first of these is a deviation in which some other effect occurs concurrently with the design intention. The guide words are AS WELL AS and the deviation AS WELL AS TRANSFER A. This could mean

- i The transfer of some component in addition to A. A search of the flowsheet in Figure 1 shows an additional line with an isolation valve on the pump suction. If this valve were not shut, another component might be transferred together with A. This raises the possible effects of such a component either in its own right or as an inert diluent of A
- ii The transfer of A somewhere else in addition to its transfer to the reactor. Inspection of the flowsheet shows this is possible. It could for example flow up the line on the suction side of the pump
- iii The carrying out of another activity concurrently with the transfer. For example, can A boil or decompose in the pipelines or pump?

The other related deviation is that which occurs when the design intention is incompletely achieved. The guide words are PART OF and the deviation PART OF TRANSFER A. This could mean

- i A component of A is missing. Here a knowledge of the composition of A is required so the effects of the missing component can be assessed
- ii The omission of one or more reactors if the pump delivers A to more than one reactor.

The final two deviations are again qualitative but none of the original design intention is retained. The first of these is the opposite of the design intention. The guide word is REVERSE and the deviation REVERSE TRANSFER OF A. This means flow from the reactor back through the pump. The flowsheet is examined to see if this is possible and the consequences are assessed.

Lastly, there is the complete substitution of the design intention by something else. The guide words are OTHER THAN and the deviation is OTHER THAN TRANSFER A. This could mean

- i The transfer of a different material. The flowsheet is examined to see if this is possible. Substitution could arise in a number of ways. For example, the wrong material could be delivered or another material admitted via the T piece on the suction side of the pump. Information would be gathered on possible materials and their effects
- ii A change in the implied destination, ie transfer of A somewhere other than the reactor. Inspection of the flowsheet shows that this can happen via the T piece
- iii A change in the nature of the activity. For example, can A solidify instead of being transferred?

The general objectives for a study are normally set by the person responsible for the project or for the plant; for example, the project manager, project engineer or the plant manager. He is usually assisted in this definition by a study leader (see 3.2). The study will be carried out by a team and the degree of authority given to that team must be decided. The definition is made easier if the manager has an appreciation of the approach; training courses for managers are discussed in Appendix 5.

3.2 Team composition

Hazard and Operability Studies are normally carried out by multi-disciplinary teams. There are two types of team member, namely those who will make a technical contribution and those who play a supporting and structuring role.

Technical team members

The examination requires the team to have a detailed knowledge of the way the plant is intended to work. This means a blend of those concerned with the design of the plant and those concerned with its operation. The technique of using guide words generates a very large number of questions. For most purposes it is essential that the team contains enough people with sufficient knowledge and experience to answer the majority of those questions without recourse to further expertise.

As an example, a typical small chemical plant would be examined by a team consisting of each of the following

- Mechanical engineer
- Chemical engineer
- R & D chemist
- Production manager
- Project manager responsible for the project as a whole

This group should contain sufficient expertise to provide the necessary technical input. Additionally if some members of the team are drawn from those who also have some responsibility for the design of a plant, they will be particularly motivated to produce a successful design and a safe operating procedure. Normally these members of the team will have the necessary authority to make changes. The blend of disciplines will vary with the type of project. Some projects will require the inclusion of different disciplines for example

- Instrument and electrical engineers
- Civil engineers
- Pharmacists, etc

The team should not be too large, ideally between three and five technical members. If a study seems to require a large number of people it is worthwhile trying to break it down into several disparate parts with some variation of team composition for each part.

The training of team members is discussed in Appendix 5.

Supporting team members

Because examination sessions are highly structured and very systematic, it is necessary to have someone to control the discussion. We will call this person the 'study leader'.

The study leader has a role to play throughout a study He should help whoever has commissioned the study to define its scope. He may help with the selection and training of the team. He will advise on the assembly of the necessary data and may help convert this into a suitable form. However, his most obvious role emerges during the examination sessions where he guides the systematic questioning and he must be thoroughly trained for this job. It is not desirable that he should be responsible for making a major technical contribution. If possible, he should not have been closely associated with the subject of the study as there is a danger of developing blind spots and failing to use the technique objectively. But he should have sufficient technical knowledge to be able to understand and control the team discussions. The characteristics and training required are discussed in Appendix 5.

In addition to the study leader it is sometimes desirable to have a further supporting member of the team to make a note of the hazards as they are detected. This person is known as the study 'secretary' or 'scribe'. It may appear extravagant to employ two people in a supporting role. However, experience indicates that this arrangement greatly increases the rate of working of the team as a whole. It is better to employ seven people for two days rather than six people for four days on a given study. The training of secretaries is also discussed in Appendix 5.

The attitude of team members

It is imperative that the team as a whole should have a positive and constructive attitude to a study as its success ultimately depends upon the imaginative thinking of the members.

This positive attitude must be built up from the definition stage onwards. Suitable training is a great help and should create a climate in which the team members are anxious to start the study. At times during the examination sessions, some team members feel the approach is tedious but a well-led team ultimately derives considerable satisfaction from its design work receiving such a thorough analysis.

3.3 Preparative work

The amount of preparative work required depends upon the size and complexity of the plant. In the simplest case, a group of people can work together for a couple of hours on a simple flowsheet and complete a study. In general, rather more preparation is required. The preparative work consists of four stages

- i Obtain the data
- ii Convert the data into a suitable form
- iii Plan the sequence for the study
- iv Arrange the necessary meetings

Typically, the data consists of various drawings in the form of line diagrams, flowsheets, plant layouts, isometrics and fabrication drawings. Additionally there can be operating instructions, instrument sequence control charts, logic diagrams and computer programmes. Occasionally there are plant manuals and equipment manufacturers' manuals.

The data must be inspected to make sure it is sufficiently comprehensive to cover the defined area of study and any discrepancies or ambiguities in the data must be resolved. The amount of work required to convert the data into a suitable form and plan the sequence for the study varies with the type of plant.

With continuous plants the preparative work is minimal. The existing flowsheets or pipe and instrument diagrams contain sufficient information for the study and it is merely necessary to see that there are enough copies of each drawing available. Likewise the sequence for the study is straightforward. The study team starts at the beginning of the process and progressively works downstream. A list of typical plants of this type together with a worked example of part of a study are shown in Appendix 1.

In view of the relative simplicity of the study of continuous processes, most of this section and the greater weight of material in the worked examples (see Appendices 2 and 3) are devoted to the more complex situations found in batch operations.

With batch plants the preparative work is usually more extensive. In addition to drawings which describe the plant itself, it is necessary to know the sequence of plant operations. This can be in a variety of forms—for example running instructions, logic diagrams or instrument sequence diagrams. In some circumstances (eg when more than one batch of material is being processed at the same time) it may be necessary to prepare a display indicating the status of each vessel on a time basis. Again, operators may be physically involved in the process (eg in charging vessels) as opposed to simply controlling the process and their activities will need to be represented by means of flow process charts.

Sometimes it will not be possible to start at the beginning of a flowsheet and work downstream. Instead the team will start with the first operating instruction and apply the guide words to it (or to part of it) and refer to the line diagram, flow process charts, etc. The study leader will usually prepare a plan for the sequence of study before the study starts. A list of typical plants of this type together with a simplified example is given in Appendix 2.

With some kinds of complicated, proprietary items of equipment, the preparative work can be extensive and occupy more man-days than the examination itself. Equipment manufacturers rarely supply sufficient information in a form suitable for a study, and as a rule flowsheets do not exist which show the full integration of a proprietary item of equipment with existing plant. Occasionally several proprietary items from different manufacturers are assembled in series.

The study leader will often have to prepare a suitable model tailored to suit the application of the technique to the equipment. This may include a display of its relationships with operators and with other plant. This preparative work will often involve a lengthy dialogue between the project engineer and the study leader and sometimes involves the manufacturers as well. The study leader will prepare a plan for the study and discuss both the model and the plan with the team prior to starting the study. A list of typical equipment which might be treated in this way and an example are given in Appendix 3.

Once the data has been assembled and the model made (if necessary) the study leader is in a position to start to arrange meetings. The first requirement is to estimate the team-hours needed for the study. This can be built up in a number of ways. As a general rule each individual part to be studied, eg each main pipeline into a vessel, will take an average of fifteen minutes team time. The simple example shown in Figure 1 should take one and a half hours made up of fifteen minutes each for the two inlets, two exits, the vent and the vessel itself.

Thus an estimate can be made by considering the number of pipelines and vessels. Another way to make a rough estimate is to allow two and a half hours for each vessel. Fifteen minutes should also be allowed for each simple verbal statement such as 'switch on conveyor', 'motor starts', 'conveyor starts'.

Having arrived at an estimate of the team hours required, the study leader (or secretary) can consider arranging meetings. Ideally the duration of examination sessions should be restricted to three hours (preferably in the morning). Longer periods of examination are undesirable because it is usually found that effectiveness begins to fall off. Under extreme time-pressures, examination sessions have been held for two consecutive days but such a programme should be attempted only in very exceptional circumstances.

Ideally there should be not more than two sessions per week to allow for the follow-up work described in Section 3.5. This might give rise to difficulties when individual members of the team have to travel to the meeting place.

Examination sessions should be arranged to be carried out in rooms which are free from distractions and with plenty of table space for flowsheets, charts, etc.

With large capital projects, it is often found that one team cannot carry out all the studies within the time constraints imposed. It may therefore be necessary to use a multiplicity of teams and team leaders. One of the team leaders should then act as a co-ordinator and allocate sections of the design to different teams and prepare time schedules for the study as a whole.

3.4 The examination in practice

The principles have already been described in Section 2 and the purpose of this chapter is to add practical advice on how these principles are put into effect.

Examination sessions are highly structured with the study leader controlling the discussion by following his predetermined plan. If the approach is based on the flowsheet he selects the first vessel and asks the team to explain its broad function. He selects the pipeline or other element of the design and asks the team to make its purpose explicit. This is not always straightforward but until every member of the team knows exactly what something is supposed to do, deviations cannot be generated. A similar approach is used if the study sequence is based on operating instructions.

The study leader then applies the first guide word and the team discussion starts. It is sometimes necessary, particularly with an inexperienced team, for the study leader to stimulate the team discussion by asking further questions such as 'Can the flow stop?' or 'Does it matter if it stops?' As far as possible only probing questions should be asked by the study leader. The team should not only provide the technical answers but be encouraged to be creative and think of all the deviations and hazards themselves.

As hazards are detected the study leader should make sure everyone understands them. As mentioned earlier, the degree of problem-solving during the examination sessions can vary. There are two extreme positions

i A solution is found for each hazard as it is detected before looking for the next hazard
ii No search for solutions is started until all hazards have been detected

In practice there is a compromise. It may not be appropriate or even possible for a team to find a solution during a meeting. On the other hand, if the solution is straightforward and local, a decision can be taken and the design and operating instruction modified immediately. To some extent, the ability to take instant decisions depends upon the type of plant being studied. With a continuous plant, a decision taken at one point in a design may not invalidate previous decisions concerning parts of the plant upstream which have already been studied. But this possibility always has to be considered. For batch plants with sequence control, any alteration to the design or mode of operation could have extensive implications.

If a question is noted for future evaluation, a note is also made of the person nominated to follow it up.

The study leader should sum up at the end of the team discussion before starting with the next guide word. However, he must maintain sufficient pace to avoid the team becoming bored and also he must keep as far as possible to an agreed timetable. To this end it may be necessary to terminate an erudite discussion between two experts by suggesting the point of disagreement be noted and resolved outside the meeting.

Although the study leader will have prepared for the study, the technique is very penetrating and may expose gaps in the model or in the knowledge of the team members. It may sometimes be necessary to elaborate on some aspects during the meeting or even postpone certain parts of the study in order to obtain more information.

Once a section of pipeline or a vessel or an operating instruction has been fully examined, the study leader should mark his copy to this effect. This ensures comprehensive coverage. Another way of doing this is that once every part of a drawing has been examined, the study leader certifies that the examination has been completed in an appropriate box in the flowsheet.

It has already been mentioned that sometimes a study secretary is used as well as a study leader. Secretaries are frequently employed in either of the following circumstances

i When the examination must be carried out very quickly because of time pressures on members of the team
ii The study is complex and the leader must guide the team using a number of sources of information simultaneously, eg a combination of flowsheets, operating instructions, sequence control charts and bar-charts. The use of a secretary enables the leader to concentrate on directing the study

3.5 Follow-up work

The follow-up to the examination sessions is generally straightforward. If decisions have been taken concerning changes in design or operating methods, these must be communicated to those responsible. Any outstanding problems must be resolved by obtaining more information followed by action and there must be some form of progress-chasing.

Sometimes the output from examination sessions consists largely or exclusively of questions to be answered later. A list of these may be compiled by the study leader (or secretary) and circulated to the team members. After an interval the team reconvenes in what are called 'Evaluation and action sessions'. At these, each question is reviewed, progress is noted and where possible, decisions taken. One evaluation and action session can usually deal with the output of two or three examination sessions.

Once a hazard has been discovered, the kind of action needed to provide a safe system will usually be agreed quite quickly because in many cases there is an obvious remedy to hand. However in some cases it will become apparent that there are a number of possible actions and the team may have some difficulty in agreeing which is the most effective course to take. Actions to contain hazards are generally of four kinds

i A change in the process (recipe, materials, etc)
ii A change in process conditions (pressure, temperature, etc)
iii An alteration to the physical design
iv A change of operating method

It is important to consider a wide range of possible actions and not to except that every hazard can and should be contained merely by an alteration to the physical design.

When choosing between a number of possible actions it may be useful to put them into two categories

i Those actions which remove the cause of the hazard
ii Those actions which reduce the consequences

In general it is better and more effective to remove the hazard and provided the study is carried out at the design stage this can usually be done without undue expenditure (see also Section 4.1). If there is no reasonable prospect of removing the hazard the team will have to consider what can be done to protect people and plant if the accident takes place.

The study leader then applies the first guide word and the team discussion starts. It is sometimes necessary, particularly with an inexperienced team, for the study leader to stimulate the team discussion by asking further questions such as 'Can the flow stop?' or 'Does it matter if it stops?' As far as possible only probing questions should be asked by the study leader. The team should not only provide the technical answers but be encouraged to be creative and think of all the deviations and hazards themselves.

As hazards are detected the study leader should make sure everyone understands them. As mentioned earlier, the degree of problem-solving during the examination sessions can vary. There are two extreme positions

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ii No search for solutions is started until all hazards have been detected

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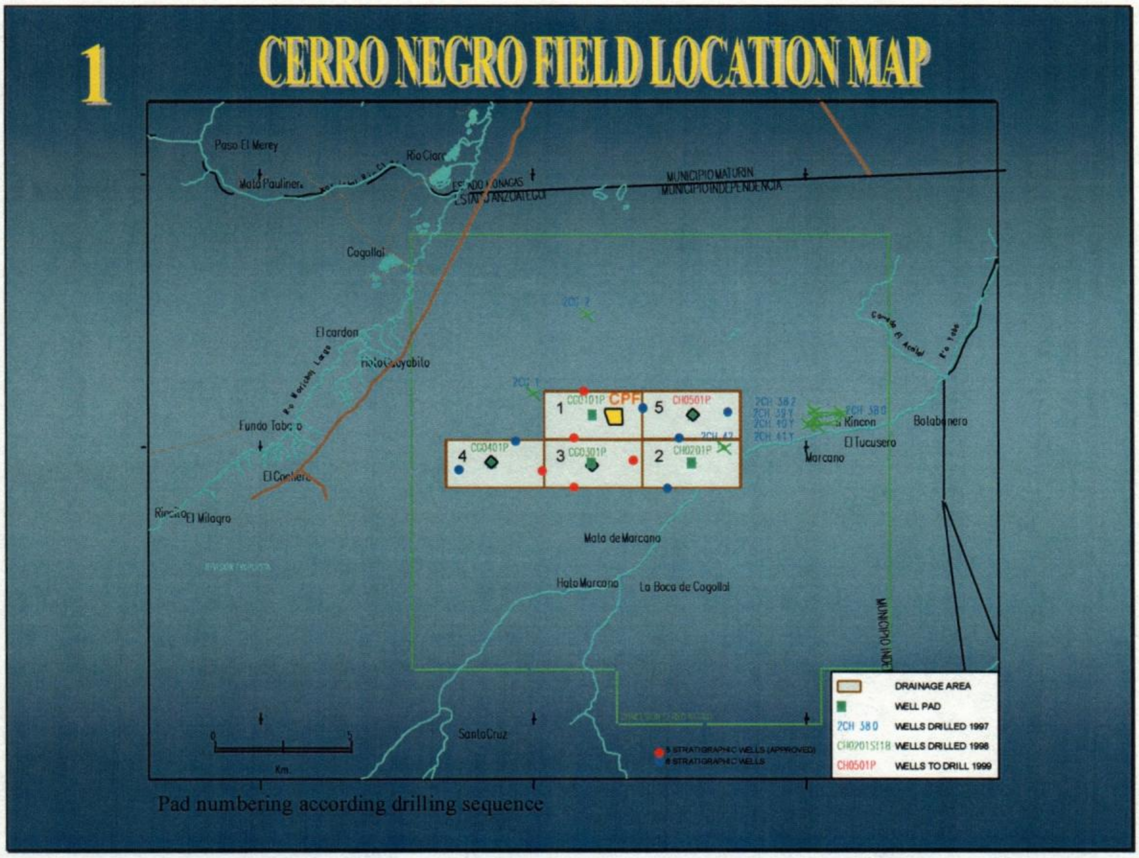
CAPITULO 3

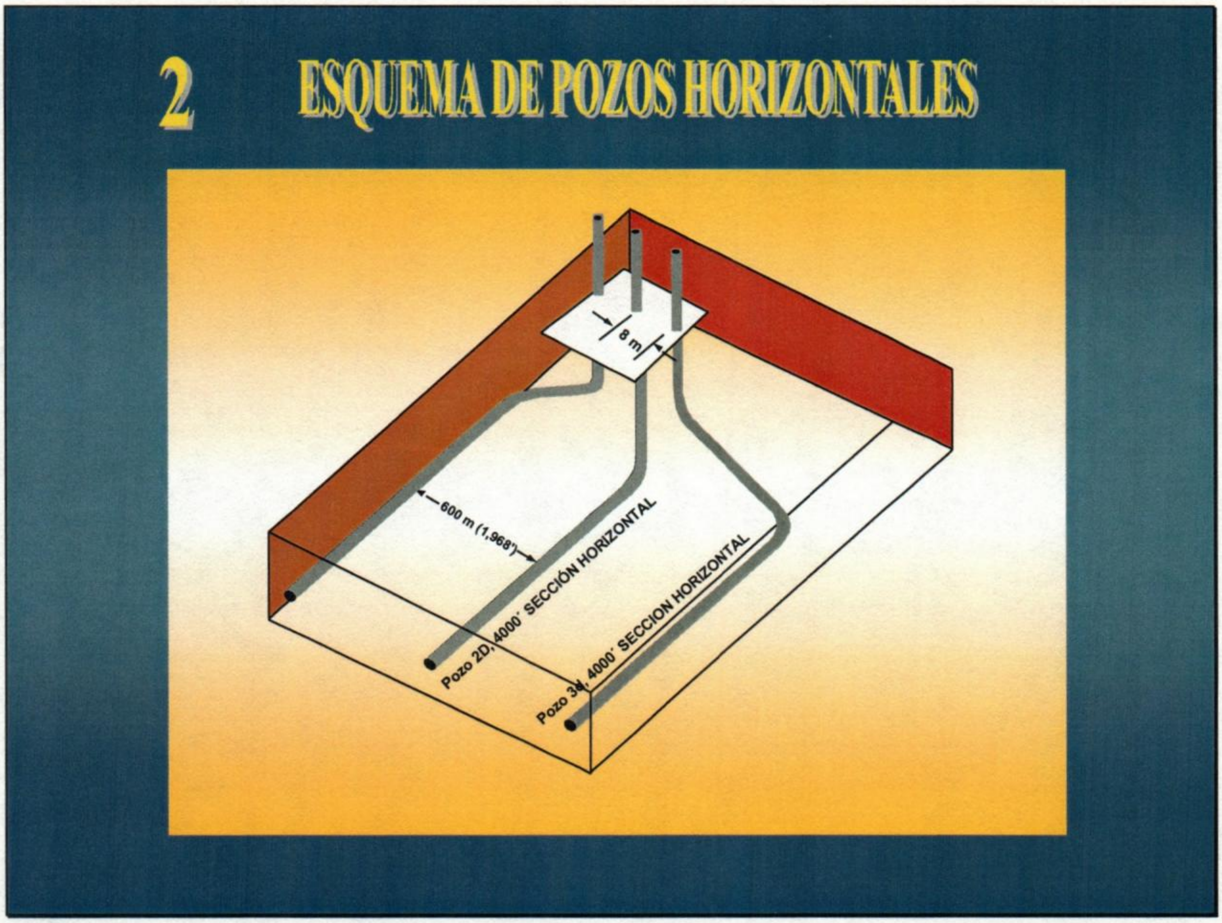
PRODUCCIÓN
PROYECTO CERRO NEGRO

ANEXO N° 1



Pad numbering according drilling sequence

ANEXO N° 2


2
ESQUEMA DE POZOS HORIZONTALES
8 m
600 m (1,968')
Pozo 2D, 4000´ SECCIÓN HORIZONTAL
Pozo 3
4000´ SECCION HORIZONTAL

ANEXO N° 3

Obras a ejecutar para la perforación de los pozos

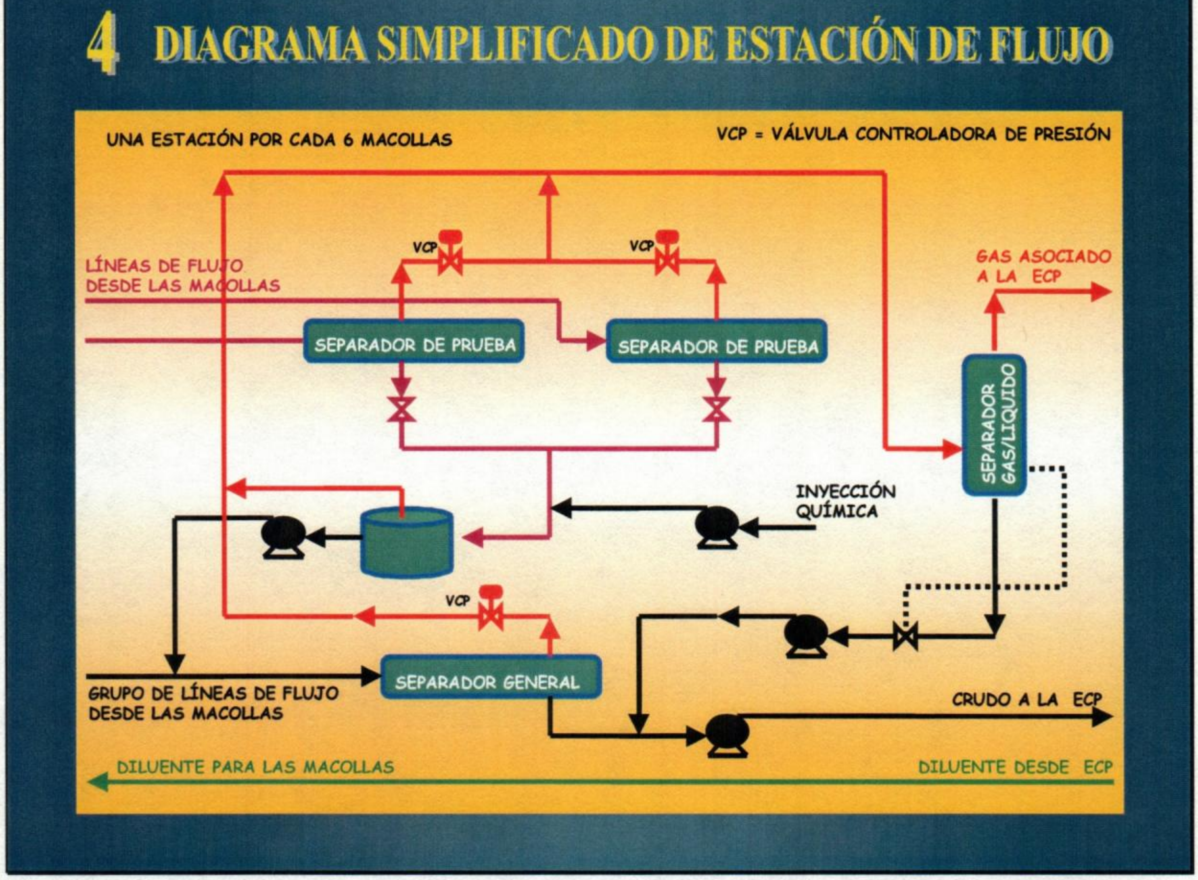
La perforación de los pozos se realizará mediante el método de perforación rotatoria, con motores de fondo y equipos de medición y control direccional. En el proceso de perforación, se utilizarán lodos de perforación a base de agua con aditivos químicos para prevenir el hinchamiento de arcillas, control de filtrado y otras propiedades reológicas del lodo de perforación.

El lodo se bombeará desde los tanques de mezcla hacia la tubería de perforación y saldrá por el fondo, a través de la mecha de perforación, arrastrando los fragmentos de rocas (ripios) resultantes de la penetración en el subsuelo. La mezcla de lodo y ripios fluirá a la superficie a través del espacio anular comprendido entre la tubería de perforación y la pared del hoyo.

A través de un proceso de separación, los lodos serán recolectados en un tanque donde se acondicionarán para recircularlos nuevamente al pozo, y los ripios, se pasarán a través de un tornillo sin fin y se tratarán a través del sistema de mezcla con suelos ("Landfarming"). El esquema de perforación del Proyecto contempla la perforación de pozos horizontales y altamente inclinados (aproximadamente 84°) que permitan drenar efectivamente las arenas superiores, medias e inferiores del miembro Morichal, tal como se muestra en la Figura 14. Estos pozos tendrán una longitud de 2000 pies de sección horizontal basados en la experiencia actual del área , sin embargo en la medida que se disponga de mayor experiencia y la continuidad de las arenas lo permitan, esta sección horizontal pudiera ser mayor (hasta unos 4000 pies). Esto se infiere de los análisis de simulación realizados recientemente, incorporando las experiencias del programa de perforación confirmatorio y de la interpretación sísmica hasta la fecha. Sin embargo esto requiere de mayor estudio y mayor historia de producción de campo.

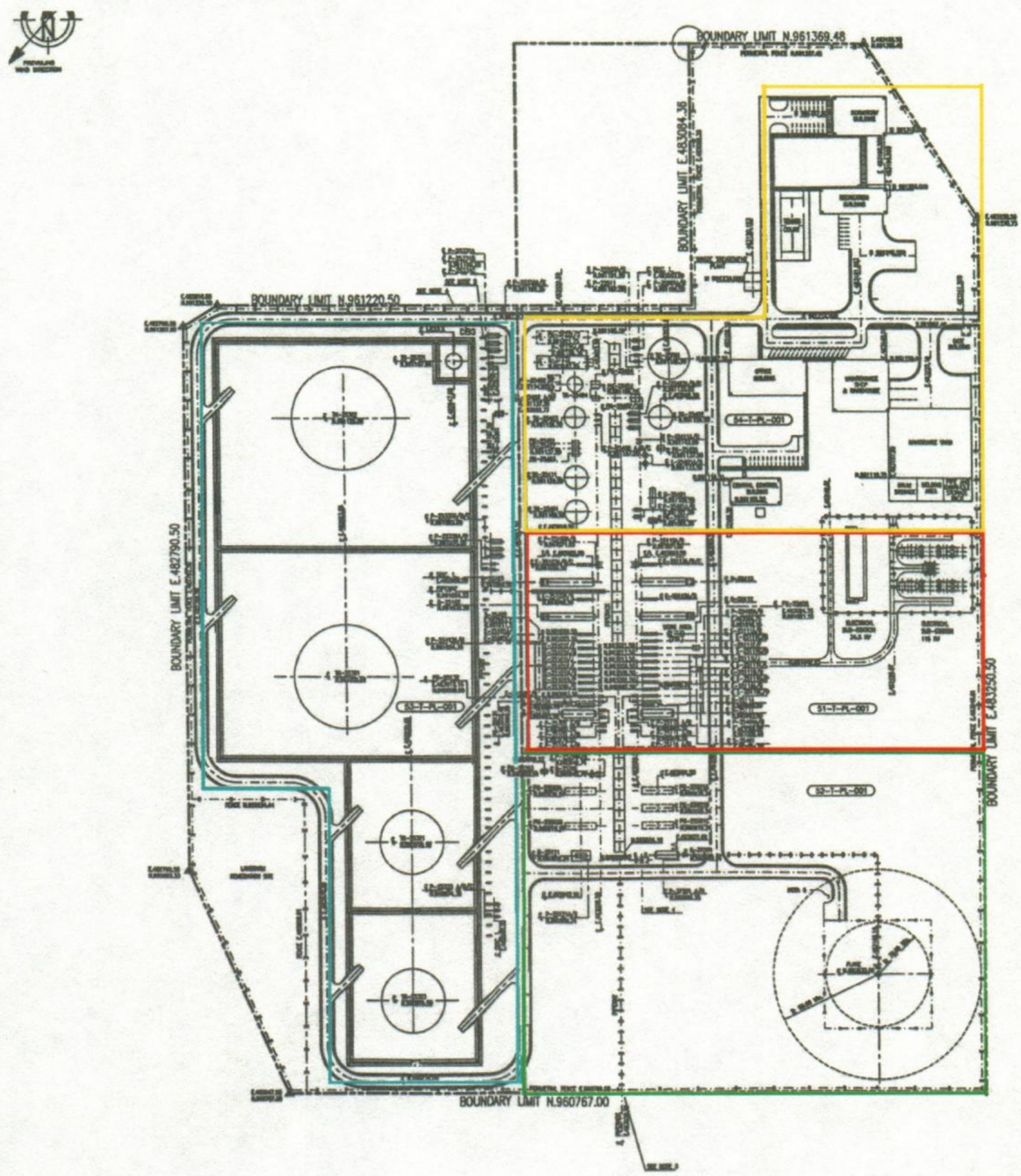
Estos pozos se perforarán utilizando la técnica de perforación de radio medio con ángulos de construcción del hoyo entre 5 y 8 grados por cada 100 pies, partiendo en superficie de una misma localización y logrando un espaciamiento en el subsuelo entre 400 y 600 metros, según sea el caso que finalmente resulte más adecuado. Las macollas agruparán 12 pozos en superficie dependiendo de la geología del área, y los mismos tendrán diseños bidimensionales o tridimensionales, según estén ubicados en el centro o en los extremos de la macolla.

ANEXO N° 4


4 DIAGRAMA SIMPLIFICADO DE ESTACIÓN DE FLUJO
UNA ESTACIÓN POR CADA 6 MACOLLAS
VCP = VÁLVULA CONTROLADORA DE PRESIÓN
VCP
VCP
LÍNEAS DE FLUJO DESDE LAS MACOLLAS
GAS ASOCIADO A LA ECP
SEPARADOR DE PRUEBA
SEPARADOR DE PRUEBA
SEPARADOR GAS/LIQUIDO
INYECCIÓN QUÍMICA
VCP
GRUPO DE LÍNEAS DE FLUJO DESDE LAS MACOLLAS
SEPARADOR GENERAL
CRUDO A LA ECP
DILUENTE PARA LAS MACOLLAS
DILUENTE DESDE ECP

ANEXO N° 5

PLOT PLAN DEL CPF

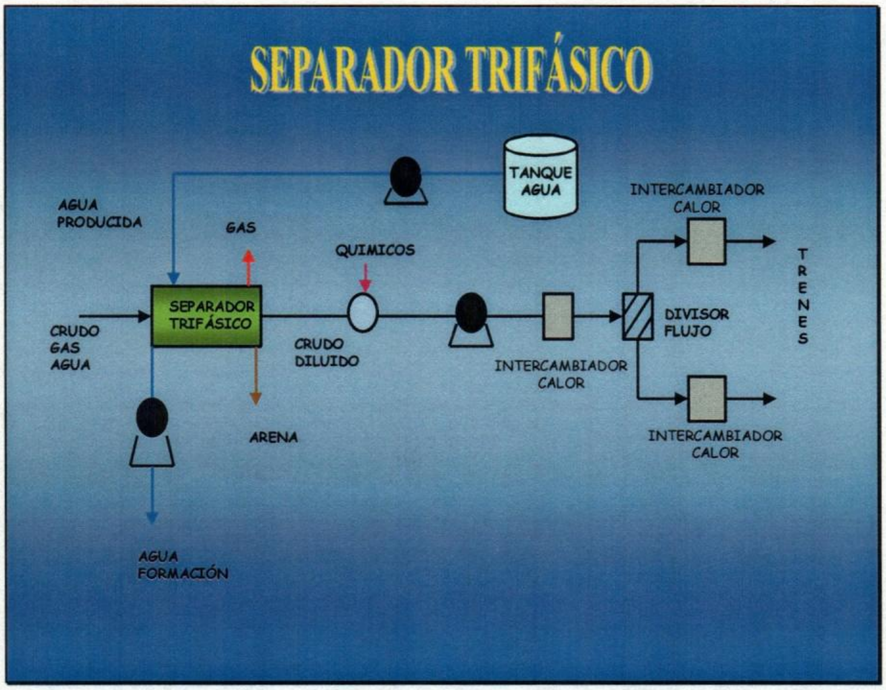


LEYENDA

- AREA DE ALMACENAMIENTO
- AREA DEL SISTEMA DE COMPRESIÓN DE GAS
- AREA DE TRATAMIENTO DE CRUDO
- AREA DE SERVICIOS

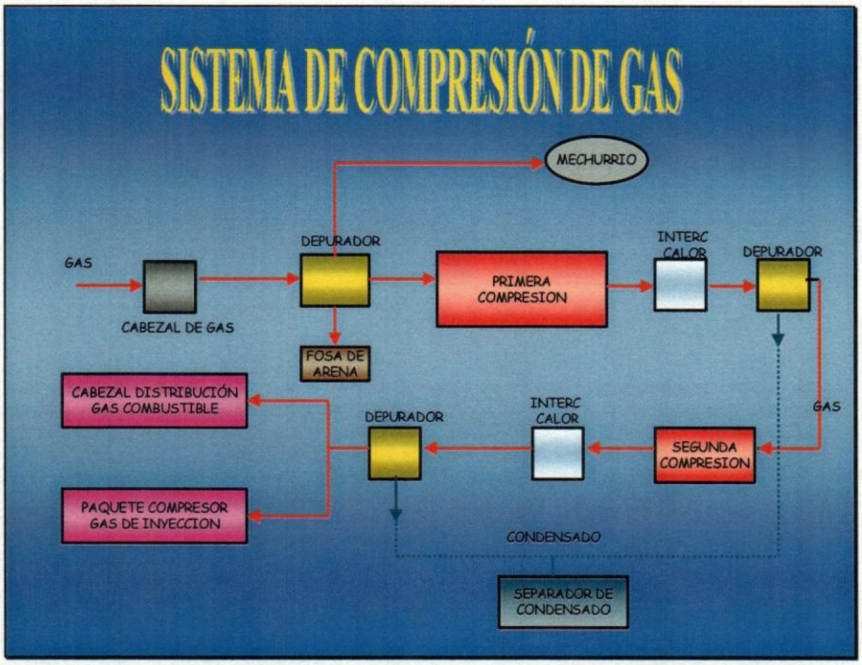
ANEXO N° 6

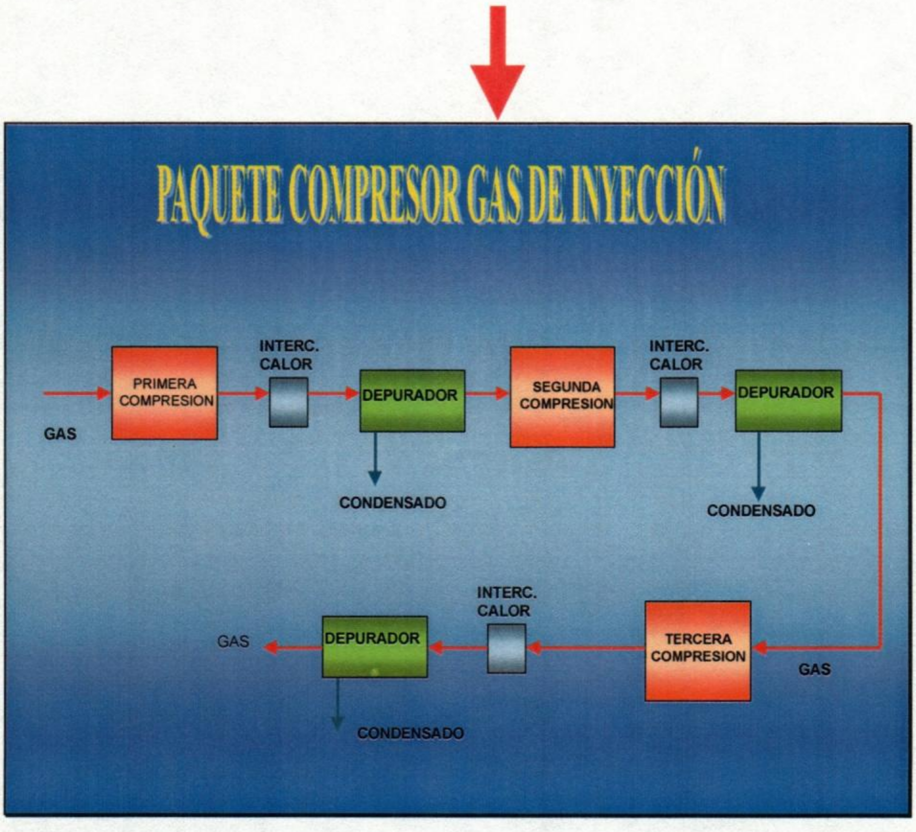
DIAGRAMA DE FLUJO ÁREA DE TRATAMIENTO DE CRUDO



ANEXO N° 7

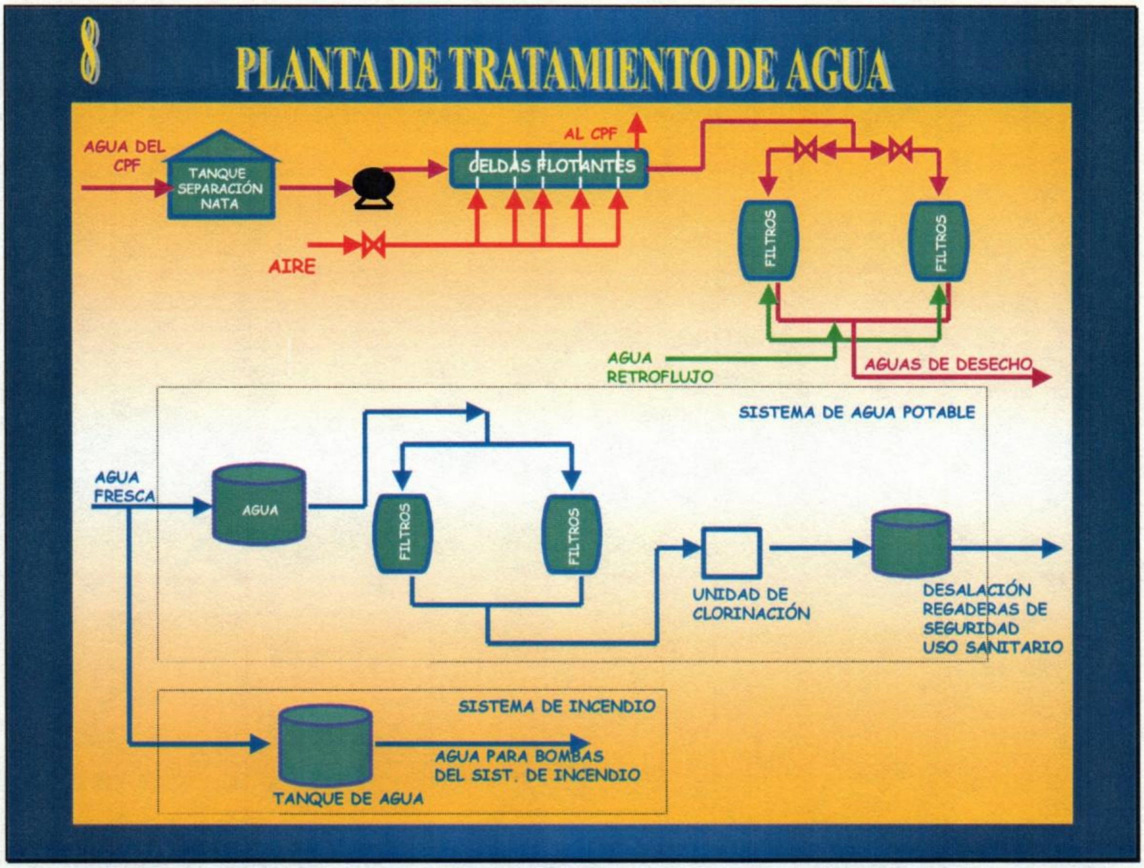
DIAGRAMA DE FLUJO ÁREA Del SISTEMA DE COMPRESIÓN DE GAS





ANEXO N° 8

DIAGRAMA DE FLUJO PLANTA DE TRATAMIENTO DE AGUA



CAPITULO 4

METODOLOGÍA

ANEXO N°1

HEALTH EFFECTS OF HYDROGEN SULFIDE

HEALTH EFFECTS OF HYDROGEN SULFIDE

Hydrogen Sulfide is generally noted by its characteristic rotten egg odor. This odor is readily recognizable in low concentrations. Prolonged exposure to hydrogen sulfide — or even short exposures at 30 ppm and above - will affect olfactory senses and prevent detection of hydrogen sulfide by sense of smell. This is important, since you may not be able to depend on your sense of smell to warn you of the presence of this gas.

Hydrogen Sulfide is an irritant. It will adversely affect your eyes and respiratory tract, causing irritation that may lead to severe pain and incapacitation.

In high concentration, death can occur rapidly.

Current ACGIH exposure levels for hydrogen sulfide gas is 10 ppm as a time weighted average with a short-term exposure limit (STEL) of 15 ppm for 15 minutes. In any case, exposures to hydrogen sulfide in concentrations above the exposure limits should not be permitted without the protection of a self-contained breathing apparatus. Caution should be observed to protect ears, especially on individuals who are aware of having perforated ear drums. These small openings have been indicated in the death of individuals who were overcome by hydrogen sulfide even while wearing effective respiratory protection, due to the gas entering the body through these perforations.

H_2S Concentration — PPM	Effect
0 to 10	Can smell — no adverse effects should be encountered during an 8-hour exposure.
10 to 20	Eye irritation.
20 to 100	Inflammation, corneal blistering and opacity of the eye, loss of the sense of smell, headache, cough, nausea.
100 to 300	Respiratory difficulty, pulmonary edema, respiratory depression and irritation.
300 to 600	Central and peripheral nervous system effects indicated by tremors, weakness, numbness of extremities, unconsciousness and convulsions.
600 to 1000	Rapid unconsciousness resulting in death if emergency aid is not promptly administered.
1000 and above	Immediate cessation of breathing and death.

ANEXO N° 2

CLASIFICACIÓN DE LOS CRUDOS

Los crudos procedentes de diferentes depósitos e incluso de distintos pozos de un mismo yacimiento se diferencian unos de otros por sus propiedades físicas y químicas. Es sabido que precisamente las propiedades del petróleo determinan la orientación de su proceso de tratamiento y refinación, e influyen en forma decisiva en la calidad de los productos de petróleo obtenidos. La clasificación de los crudos resulta una ayuda para elegir el tipo de proceso de refinación, pues refleja la naturaleza química de los crudos.

Existen las más diversas clasificaciones químicas, genéticas, industriales y comerciales de los crudos, sin embargo, centraremos la atención en la clasificación de los crudos según PDVSA en función de su gravedad, su contenido de azufre y su naturaleza química.

En base a la densidad

De acuerdo a la densidad, los crudos se clasifican en:

	° API	**Gravedad Específica**
Livianos	> 30	< 0.876
Medianos	22 – 29.9	0.887 – 0.922
Pesados	10 – 21.9	0.922 – 0.999
Extrapesados	< 10	> 1.000

Los crudos livianos dan alto rendimiento de gasolina y por lo general tienen bajo contenido de azufre. Típicamente, de los livianos y medianos se obtienen aceites lubricantes. Los crudos pesados y extrapesados se caracterizan por su alto contenido de resinas, así que para obtener aceites a partir de estos, es necesario emplear métodos con solventes selectivos, absorbentes, etc. Sin embargo, los crudos pesados y extrapesados constituyen la mejor materia prima para la producción de asfalto.

El conocimiento de la densidad de los crudos da una idea de las cantidades de los cortes a ser obtenidos, pero no indica la calidad. El contenido de azufre constituye un factor de la calidad general.

En base al azufre

De acuerdo a su contenido de azufre, los crudos se clasifican en:

	S. % Peso
Crudos de bajo azufre (dulces)	< 0.5
Crudos de mediano azufre	0.51 – 2.0
Crudos de alto azufre (ácido)	> 2.0

El contenido de azufre nos indica la calidad que es posible obtener en los diferentes cortes del crudo, y si se requiere de procesos de tratamiento para su comercialización.