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Water-Alternating-Gas (WAG) Injection a Novel EOR Technique for Mature Light Oil Fields - A Laboratory Investigation for GS-5C sand of Gandhar Field.

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Summary

It is an established fact that substantial amount of oil usually remains in a reservoir after primary and secondary processes. There is an enormous incentive for development of a field through suitable EOR methods aimed at recovering some portion of the remaining oil.

In recent years there has been an increasing interest in water alternating-gas (WAG) processes. For the fields reviewed, a common trend for the successful injections is an increased oil recovery in the range of 5 to 10% of the oil initially in place (OIIP). WAG injection is an oil recovery method initially aimed to improve sweep efficiency during gas injection. In some recent applications produced hydrocarbon gas has been reinjected in water injection wells with the aim of improving oil recovery and pressure maintenance. Oil recovery by WAG injection has been attributed to contact of upswept zones, especially recovery of attic or cellar oil by exploiting the segregation of gas to the top or the accumulating of water toward the bottom. Because the residual oil after gas flooding is normally lower than the residual oil after water flooding, and three-phase zones may obtain lower remaining oil saturation, WAG injection has the potential for increased microscopic displacement efficiency. Thus, WAG injection can lead to improved oil recovery by combining better mobility control and contacting upswept zones, and by leading to improved microscopic displacement.

Laboratory displacement studies of WAG injection were carried out to evaluate its applicability in GS-5C sand of a matured light oil field. It is observed that the number of cycles in the WAG injection process affects the recovery of oil from the core sample. An incremental displacement efficiency of 19.3 % of Hydrocarbon Pore Volume (HCPV) is observed in the five-cycle WAG injection process as against to about 12.75 % of HCPV in single cycle WAG injection process. The WAG injection process is also verified for increasing and decreasing WAG ratio (tapering). It is observed that the tapering in WAG injection process improves the displacement efficiency. The gas tapering with increasing and decreasing WAG ratio gives incremental displacement efficiency of 20.73 % and 23.84 % of HCPV in the core pack respectively. The observations on the effect of gases revealed that the CO_2 gas with five cycle WAG process gives an incremental displacement efficiency of 40.18 % of HCPV, which is much higher than displacement efficiency of 19.3 % of HCPV in the five cycle WAG process using hydrocarbon gas.

This is possibly due to the fact that the CO_2 flooding with water may have resulted in miscible flooding at the reservoir conditions.

***Key words**: Water- alternating-gas (WAG), Oil initially in place (OIIP), Hydrocarbon Pore Volume (HCPV).*

Introduction

GS-5C reservoir is the major oil producing reservoir of said oil field. The reservoir of the field is divided into three main areas of which the central part is the major oil bearing area. The reservoir in central part contains light saturated oil and was developed under water flooding and gas injection in gas cap. Water injection in GS-5C reservoir was initiated in the year 1990 and a total of 8.95 MMm3 of water has been injected as on 01.02.2010.

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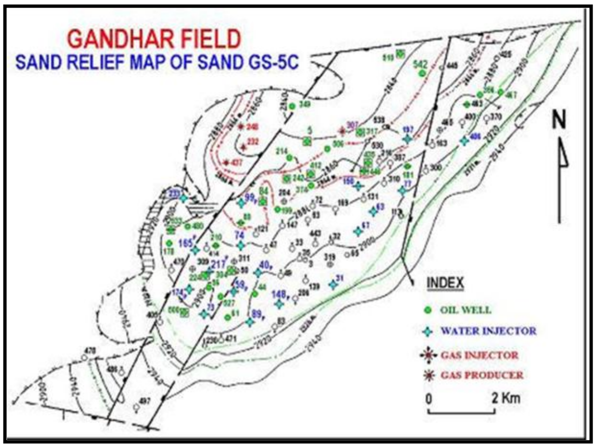


The production rates in GS-5C reservoir have been declining for the past two to three years with significant increase in water cut. As on 01.02.2010 the reservoir has produced 4.12 MMt of oil which is 38% of OIIP and 91% of Ultimate Reserves. At present GS-5C sand is producing oil @201 m3/day with an average GOR of 405 v/v and water cut of about 64% through 14 producers.

GS-5C reservoir of the field is already under water flooding and the reservoir pressure of this sand has declined drastically from its initial level of 293 kg/cm2 to 230 kg/cm2. The current reservoir pressure of GS-5C sand is far below than the bubble point pressure (270 kg/cm2) and at this pressure miscible gas injection could not be effective in improving oil recovery. A need was felt to reevaluate a purely immiscible gas injection process using some method for mobility control for improving sweep efficiency. WAG injection is a method aimed primarily to improve sweep efficiency. Additional oil recovery by WAG is expected due to contact of otherwise unswept zones of attic or cellar oil by exploiting the strength of gravity segregation of gas to the top and/or accumulating water towards the bottom. The entrapment of gas due to hysteresis and the effect of three phase flow further contribute to increased recovery by injecting immiscible gas in WAG manner. WAG injection can thus lead to improved oil recovery through combination of factors such as mobility control, contact of unswept zones, improved microscopic displacement efficiency and oil vaporization due to mass transfer between reservoir oil and injected gas.

Method

The objective of the present study was to verify experimentally if immiscible WAG could give improved microscopic displacement efficiency compared to water flooding and gas injection and to generate input data of fluid flow parameters (WAG parameters) for modeling of the WAG process.

Preparation of Core Pack: The four core plugs of 7.0 cm length and 3.8 cm diameter were cut from the native core of well "A" of GS-5C sand. The core pack was cleaned with solvent mixture (50% benzene, 25% acetone and 25% methanol) and dried in a hot air oven at a temperature of 100 OC and by passing a current of nitrogen through it. Porosity and Permeability were determined and found to be 21% and 323.23 md respectively.

Preparation of live oil: The oil and gas samples were collected separately at surface by allowing the well "B" of GS- 5C sand to flow through the test separator at GGS of destination field. The collected samples were brought to the laboratory for further analysis and testing. Both the oil and gas samples were put in a rocking cell and recombined them to get live oil at a pressure of 230 kg/cm2 and a temperature of 128 OC. The recombined oil has the following properties determined in the laboratory:

Reservoir oil density at 30^{o}C	:	0.8036 gm/cc
Stock oil density at 15.5^{o}C	:	0.8161 gm/cc
^{o}API of oil at 15.5^{o}C	:	41.5

A flash test was carried out to measure the formation volume factor and solution GOR and found to be 1.84 and 222 (v/v) respectively. The basic data used to prepare live oil and calculation of results is annexed as Table 1&2.

Table-1

Basic data of GS-5C sand of Gandhar Field		
Sl. No.	Parameters	
1	Reservoir Rock Type	Sandstone
2	Initial Reservoir Pressure (kg/cm^2)	292.7*
3	Current Reservoir Pressure (kg/cm^2)	230
4	Bubble Point Pressure (kg/cm^2)	269.6*
5	Reservoir Temperature (^{0} C)	128*
6	Density of oil (gm/cc) at 128 ^{0}C	0.5142*
7	Density of oil (gm/cc) at 15.5 ^{0}C	0.8163*
8	Stock Tank Oil Density at 15.5 ^{0}C (Recombined oil)	0.8161
9	^{0} API Gravity	41.68*
10	Oil FVF	1.84
11	Specific Gravity of Gas	0.8364
12	Solution GOR (v/v)	222
13	Core Length (cm)	20
14	Core Diameter (cm)	3.8
15	Area (cm^2)	11.37
16	Avg. Permeability (md)	323.23

Table-2

Component	Mole Fraction
N_2	0.01761
O_2	0.00730
CO_2	0.04289
C_1	0.68506
C_2	0.10387
C_3	0.08676
iC_4	0.01631
nC_4	0.02145
iC_5	0.00789
nC_5	0.00822
C_6	0.00207
C_7	0.00053
C_8	0.00002
C_9	0.00002
C_{10}	0.00000
Total	1.00000
Gas Gravity	0.8351

Experimental Details: The aim of the current work is to evaluate the performance of the different gas injection methodologies for GS-5C sand of said field. It includes comparative studies on different water-alternating-gas (WAG) injection methods and to verify their effects on the production enhancement. Core flooding experiments are performed at simulated reservoir conditions of the pressure and temperature to identify:

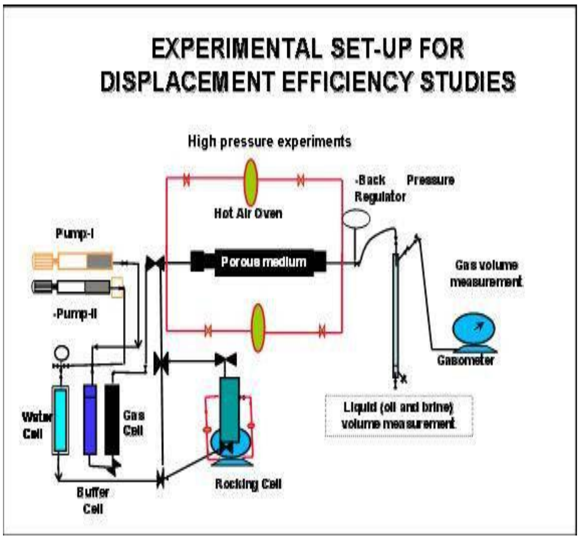
a. The effect of WAG injection method for various WAG cycles
b. To analyze displacement efficiency for different methods using different gases like hydrocarbon gas and CO2 gas at reservoir condition
c. The effect of tapering on the WAG performance

WAG processes which have been studied and discussed in this work (on the basis of WAG cycles) are,

1. Single cycle WAG using HC gas
2. Five cycles WAG using HC gas
3. Tapered WAG (with increasing and decreasing WAG ratio) using HC gas
4. Five cycles WAG using CO2 gas

Core Flood Displacement Studies: Displacement studies includes following steps during all the experiments

- Saturation with formation water.
- Determination of pore volume and absolute permeability.
- Oil flood to connate water saturation.
- Water flood to water flood residual oil saturation and tertiary immiscible single/ five cycle WAG followed by chase water.



Experimental Results and Interpretation

All the experiments were conducted at 230 Kg/cm^2 pressure & 128^{0}C Temperature, after the core pack was properly saturated with live oil at connate water saturation, water injection was started at the rate of 20cc/hr in the horizontal condition till water flood residual oil saturation. The rate of gas injection during WAG experiments was kept 10cc/hr. The experimental results presented graphically and are given as Figure 1 to 5.

Tertiary gas injection

The tertiary gas injection is carried out mainly by WAG process using hydrocarbon gas and CO_2 gas. Different WAG methods that have been applied for enhanced oil recovery are single cycle WAG, five cycle WAG (with HC gas and CO_2 separately), tapered WAG (with increasing and decreasing WAG ratio). For single cycle WAG and five cycle WAG total 1 pore volume (1 PV = 60 cc with ± 0.5 cc) of gas and water has been injected alternatively with the WAG ratio of 1:1 at the end of water flooding experiment. For tapered WAG injection method a total of 1.5 PV gas and water has been injected intermittently at the end of water flooding experiment. In tapered WAG injection the following WAG ratio (increasing and decreasing WAG ratio) as given in Table-3 have been selected and used for the experimental study.

Table-3

Cycles	WAG Ratio for Tapered WAG (Water : Gas)	
	Increasing WAG ratio	Decreasing WAG ratio
1	3:1	3:5
2	3:2	3:4
3	1:1	1:1
4	3:4	3:2
5	3:5	3:1

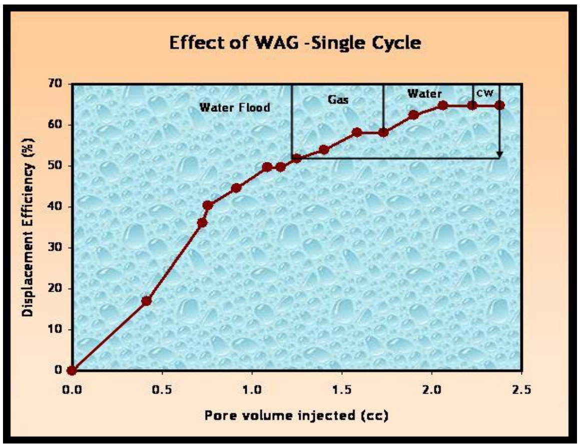


Figure – 1a : Single cycle WAG with Hydrocarbon Gas

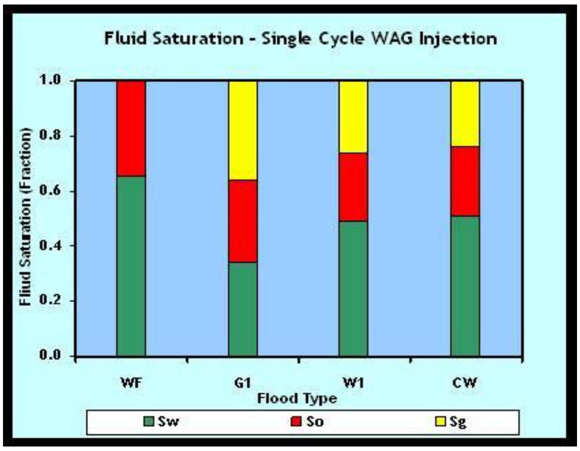


Figure –1b : Fluid Saturation – Single cycle WAG

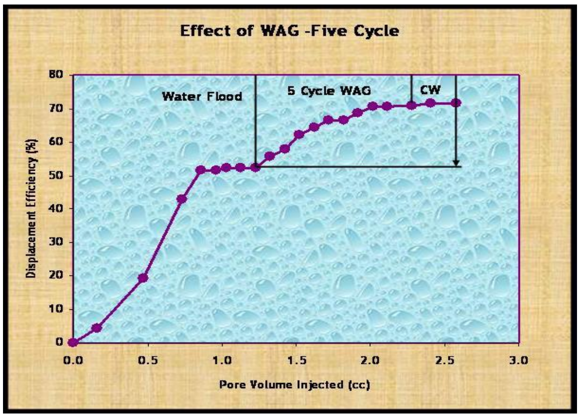


Figure – 2a : Five cycle WAG with Hydrocarbon Gas

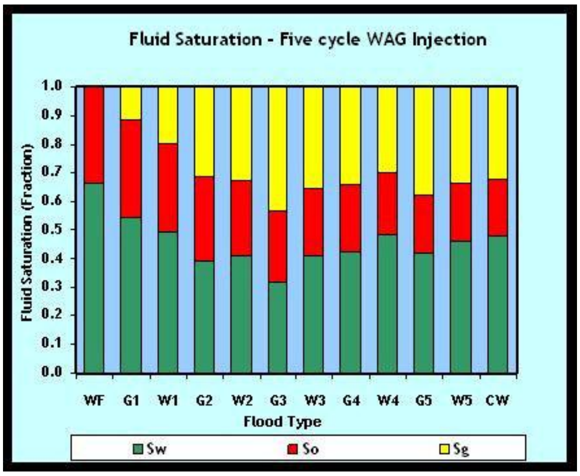


Figure –2b: Fluid Saturation – Five cycle WAG

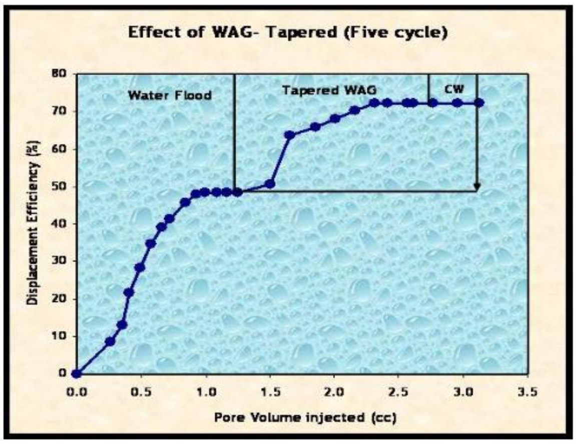


Figure – 4a : Tapered WAG with Hydrocarbon Gas

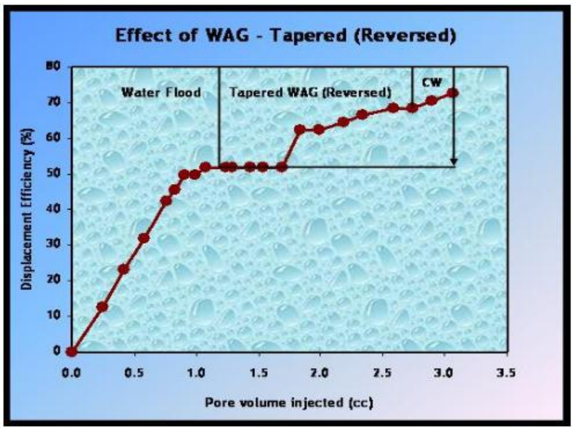


Figure –3a : Tapered WAG (Reversed) with HC Gas

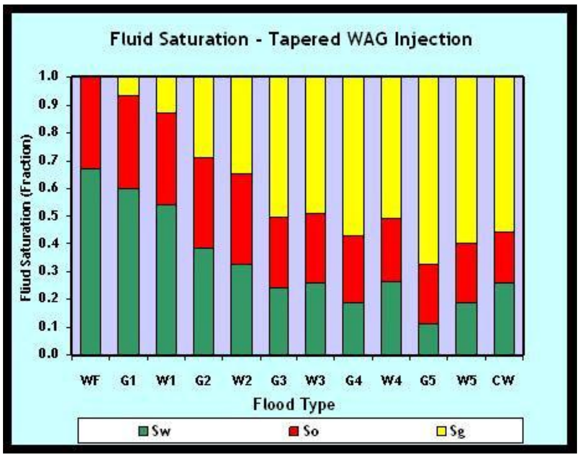
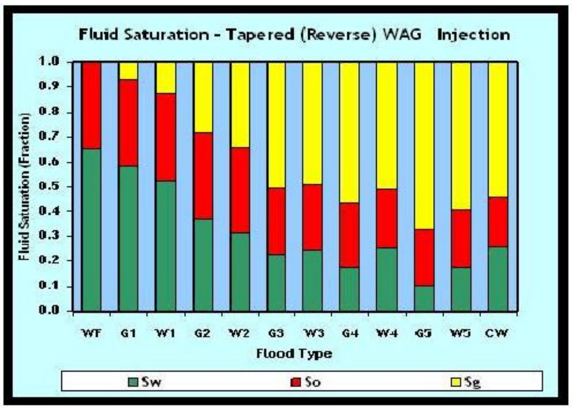


Figure – 4b : Fluid Saturation -Tapered WAG



Figure–3a : Fluid Saturation -Tapered WAG (Reversed)

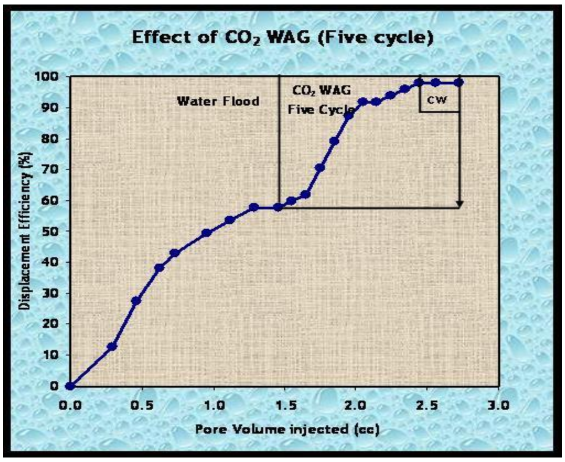


Figure –5a : Five cycle WAG with CO2 Gas

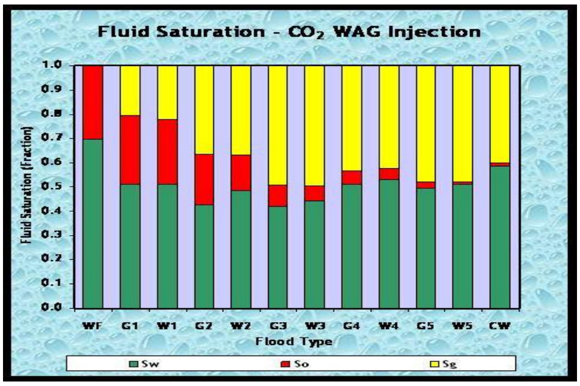


Figure – 5b : Fluid Saturation –Five cycle CO2 WAG

The maximum displacement efficiency has been noticed in CO2 five cycle injection (97.92 % of HCPV), and next maximum displacement efficiency of 72.54 % of HCPV is in tapered WAG injection (increasing WAG ratio). The maximum incremental displacement efficiency over the waterflood has been seen with CO2 gas with five cycle WAG injection (40.18% of HCPV), and the next (23.84 % of HCPV) has been noticed with tapered WAG with HC gas injection (decreasing WAG ratio). The maximum recovery with CO2 is obtained probably due to its better miscibility with the crude oil (in the core pack) at reservoir conditions as compared with the HC gas used in WAG processes. Better recovery is obtained in case of tapered WAG injection (decreasing WAG ratio) as against all WAG processes using HC gas is due to an increased sweep efficiency governed by an initial dissolution of maximum amount of gas with the crude oil in the first cycle, thus helping better mobility in the pore of the core sample. This results in an increased relative permeability of oil in the core sample which is enhanced by the subsequent water cycle in the WAG process. The summary of experimental results for WAG injection methods and Gas utilization factor for different WAG cycle are given in table-4 & table-5 respectively.

Table-4

WAG injection pattern	*Type of injection gas*	*Amount of Water injected pre-WAG process (PV)*	*Chasing water injected after WAG process (PV)*	*Total PV injected including that for WAG process*	*Recovery (%HCPV)*			
					Displacement Efficiency with water flooding	*Incremental displacement efficiency over water flood*	*Total recovery*	*Incremental displacement efficiency during chase water*
Single cycle WAG	HC gas	1.25	0.15	2.38	51.84	12.75	64.59	0
Five cycle WAG	HC gas	1.13	0.46	2.58	52.33	18.22	71.63	1.08
Tapered WAG (increasing WAG ratio)	HC gas	1.25	0.36	3.13	48.50	23.84	72.34	0
Tapered WAG (decreasing WAG ratio)	HC gas	1.24	0.33	3.07	51.82	16.50	72.54	4.23
Five cycle WAG	CO_2 gas	1.45	0.28	2.72	57.74	40.18	97.92	0

Table-5

WAG injection pattern	Type of the injection gas	Volume of gas injected during WAG process (cc)	Gas utilization factor
Single cycle WAG	HC gas	30	2.353261
Five cycle WAG	HC gas	30	1.748252
Five cycle WAG	CO_2	30	0.746269
Tapered WAG (increasing WAG ratio)	HC gas	45	1.881271
Tapered WAG (decreasing WAG ratio)	HC gas	45	2.659647

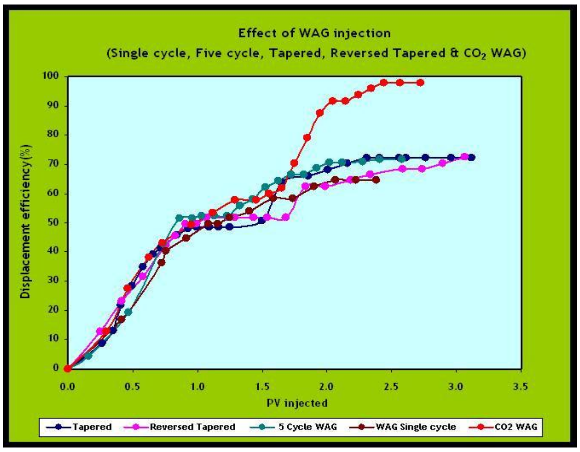


Figure-6: Composite plot of displacement efficiency of all WAG experiments.

Conclusions

The WAG injection process gives the better sweep control, mobility control of water and gas phases and improves the displacement efficiency.

The number of cycles in the WAG injection process affects the recovery of oil from the reservoir, discussion of the results shows that for the same volume of injecting fluid in single cycle and five cycle processes the incremental displacement efficiency of HCPV has been noticed as 12.75% and 19.3% correspondingly.

Tapered WAG (decreasing trend) injection results maximum recovery of 23.84% of HCPV in three cycles indicates trapped gas saturation results in improved oil recovery and residual oil saturation decreases with increasing trapped gas saturation.

CO_2 (as WAG) injection in GS-5C sand gives the displacement efficiency of about 40% of HCPV over water flood which is the indication of critical flow at the reservoir temperature and pressure which is having near miscible flow, which helps to improve the recovery of oil during WAG injection process.

Recommendations

As laboratory generated data is not sufficient enough to predict the performance in the field scale due to its obvious limitations, detailed simulation study is recommended followed by conceptualization, designing and implementation of the process in pilot scale to see the field-wide efficiency.

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